STRATEGIC PLAN

Defense Coastal/Estuarine Research Program (DCERP) Strategic Plan

SERDP Project RC-1413

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Acronyms and Abbreviations

AOC	area of concern
CAA	Clean Air Act
CAFO	confined animal feeding operation
CFR	Code of Federal Regulations
CWA	Clean Water Act
DCERP	Defense Coastal/Estuarine Research Program
DoD	U.S. Department of Defense
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FWS	U.S. Fish and Wildlife Service
GIS	geographic information systems
GSRA	Greater Sandy Run Area
HAB	harmful algal bloom
ICW	Intracoastal Waterway
INRMP	*Integrated Natural Resources Management Plan*
IPCC	Intergovernmental Panel on Climate Change
LCAC	Landing Craft Air Cushion
LCM	lifecycle management
MARDIS	Monitoring and Research Data Information System
MCBCL	Marine Corps Base Camp Lejeune
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NFESC	Naval Facilities Engineering Service Center
NOAA	National Oceanic and Atmospheric Administration
NRE	New River Estuary
OSC	On-site Coordinator
PB	prescribed burning
PI	Principal Investigator
PM	Program Manager
$PM_{2.5}$	fine particulate matter
PNA	primary nursery area
RCW	red-cockaded woodpecker
RTI	RTI International
SAB	Science Advisory Board
SAV	submerged aquatic vegetation
SERDP	Strategic Environmental Research and Development Program
SOA	secondary organic aerosol
SSA	sea salt aerosol
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
VOC	volatile organic compounds
WWTP	wastewater treatment plant

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Strategic Plan Executive Summary

Introduction

Critical military training and testing on lands along the nation's coastal and estuarine shorelines are increasingly placed at risk because of development pressures in surrounding areas, impairments due to other anthropogenic disturbances, and increasing requirements for compliance with environmental regulations. The U.S. Department of Defense (DoD) intends to enhance and sustain its training and testing assets and to optimize its stewardship of natural resources through the development and application of an ecosystem-based management approach on DoD facilities.

To accomplish the above goal, the Strategic Environmental Research and Development Program (SERDP) launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina. MCBCL provides an ideal platform for DCERP because it integrates coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems, all within the boundaries of DoD properties.

Mission Statement

DCERP's mission is to conduct Base-relevant and basic and applied research in support of an ecosystem-based management approach. The result of this research will be an understanding of the composition, structure, and function of coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems as they relate to MCBCL's military mission.

Vision Statement

The DCERP vision is for MCBCL to ensure Base sustainability by managing military operations and activities using adaptive management based on a state-of-the-art monitoring and research program. SERDP envisions that the coastal, estuarine, wetland, and terrestrial ecosystems of MCBCL will possess sufficient generality to be applied to other DoD installations along similar coastal and estuarine shorelines so that the sustainability benefits of DCERP will extend beyond the boundaries of this military installation.

Program Organization

DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering Service Center (NFESC), MCBCL, and the RTI International (RTI) DCERP Team. The overarching federal management for DCERP was assigned to NFESC. The DCERP PM is designated by NFESC and identifies the tasks and responsibilities of the RTI DCERP Principal Investigator (PI). The PI facilitates coordination with MCBCL through the DCERP On-site Coordinator (OSC). The DCERP OSC and MCBCL environmental managers will assist the DCERP PM and DCERP PI with the coordination of environmental monitoring and research activities on the Base.

Two committees will provide guidance and input to DCERP. The first, the Technical Advisory Committee (TAC), is a group of discipline experts assembled by the DCERP PM to provide scientific and technical review to ensure the quality and relevance of DCERP. The second committee, the Regional Coordinating Committee (RCC), is a group of local and regional stakeholders that serves as one of the recipients of outreach from MCBCL, the DCERP PI, and SERDP.

The RTI DCERP Team includes the PI, other environmental scientists from RTI, and researchers from the University of North Carolina Institute of Marine Sciences, North Carolina State University, University of North Carolina at Wilmington, Duke University, Virginia Institute of Marine Sciences, Virginia Tech,

University of South Carolina, National Oceanic and Atmospheric Administration (Center for Coastal Fisheries and Habitat Research, Beaufort, NC), U.S. Geological Survey (Raleigh, NC, office), URS Corporation, and Porter Scientific, Incorporated.

Goals and Objectives

DCERP's primary overarching objective is to enhance and sustain MCBCL's military mission by developing an understanding of coastal barrier, estuarine, coastal wetlands, and terrestrial ecosystem composition, structure, and function within the context of a military training environment. Specific DCERP objectives include the following: (1) develop appropriate conceptual and mechanistic ecological models to guide research, monitoring, and adaptive management feedback loops; (2) identify significant ecosystem stressors, their sources (on and off MCBCL), and their level of impact on MCBCL's ecological systems; and (3) incorporate stressor and other ecological indicator information into the models, with an aim to develop more effective management guidelines for sustainable ecosystems.

Overarching Research Strategy

The RTI DCERP Team has designed an integrative monitoring, modeling, and research strategy for MCBCL that is consistent with guidance on ecosystem-based management from the Ecological Society of America and recent recommendations from the U.S. Commission on Ocean Policy, including principles of adaptive management.

DCERP is designed to be implemented in phases. Phase I of the program represents the planning period and includes the development of an overarching research strategy (*Defense Coastal/Estuarine Research Program Strategic Plan*, henceforth referred to as the DCERP Strategic Plan), design of an ecosystem-based monitoring program (*Defense Coastal/Estuarine Research Program Baseline Monitoring Plan*, henceforth referred to as the DCERP Baseline Monitoring Plan), identification of detailed research projects (*Defense Coastal/Estuarine Research Program Research Plan*, henceforth referred to as the DCERP Research Plan), and development of a data repository design. Phase II of DCERP represents the program's implementation period and includes the execution of the DCERP Research Plan through field research; operation of the long-term ecosystem monitoring system; and collection, management, archiving, analysis, and dissemination of data from both the research and monitoring components in the DCERP data repository or data and information management system.

The Phase I planning period was conducted from November 2006 through June 2007 and consisted of four, multi-day team workshops, as well as numerous smaller group meetings and conference calls. The three planning documents that resulted from this effort were extensively reviewed by SERDP and the entire team prior to submission to the DCERP TAC for review. Comments from the TAC and SERDP Science Advisory Board (SAB) were incorporated into the Phase I planning documents before these documents were finalized.

The Phase II implementation period was started in July 2007 and will last for a minimum of 4 years. Included within the Phase II implementation period are periodic meetings with MCBCL and the TAC, as well as annual reviews by SERDP's Technical Committee for Sustainable Infrastructure and the SAB. Specific go/no-go decision points will be defined and evaluated as appropriate based on recommendations from the SERDP SAB.

Determining appropriate management decisions about military activities requires an understanding of all stressors affecting the environment, an assessment of the site-specific impact of those stressors, and an evaluation of their contribution to site degradation. Although it is understood that many factors can contribute to site-specific military impacts (e.g., frequency and intensity of training, physical characteristics of the site, meteorological conditions, legacy impacts), a consistent, quantitative evaluation

methodology appropriate for MCBCL is not currently available. During Year 1 of Phase II, the RTI DCERP Team will implement a combined research and monitoring effort that will develop a consistent approach for assessing the impact of military training for each of the ecosystems at MCBCL. Assessments will occur at two scales: landscape and plot level.

MCBCL's Natural Resource Management

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces, and all natural resources management activities on the Base must support this mission. As a military installation, MCBCL has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, MCBCL must comply with related environmental laws and regulations, such as the federal Endangered Species Act (ESA) and Clean Water Act (CWA), to ensure continuance of the military mission.

Conceptual Model Development

To facilitate the understanding of the ecosystem state and dynamics of the MCBCL region necessary to complete Phase I, the RTI DCERP Team developed an overarching conceptual model for the MCBCL region. This model includes the terrestrial lands of MCBCL, the New River Estuary (NRE), associated coastal wetlands, and the coastal barrier along Onslow Bay, as well as the overarching influence of atmospheric conditions (**Figure ES-1**).

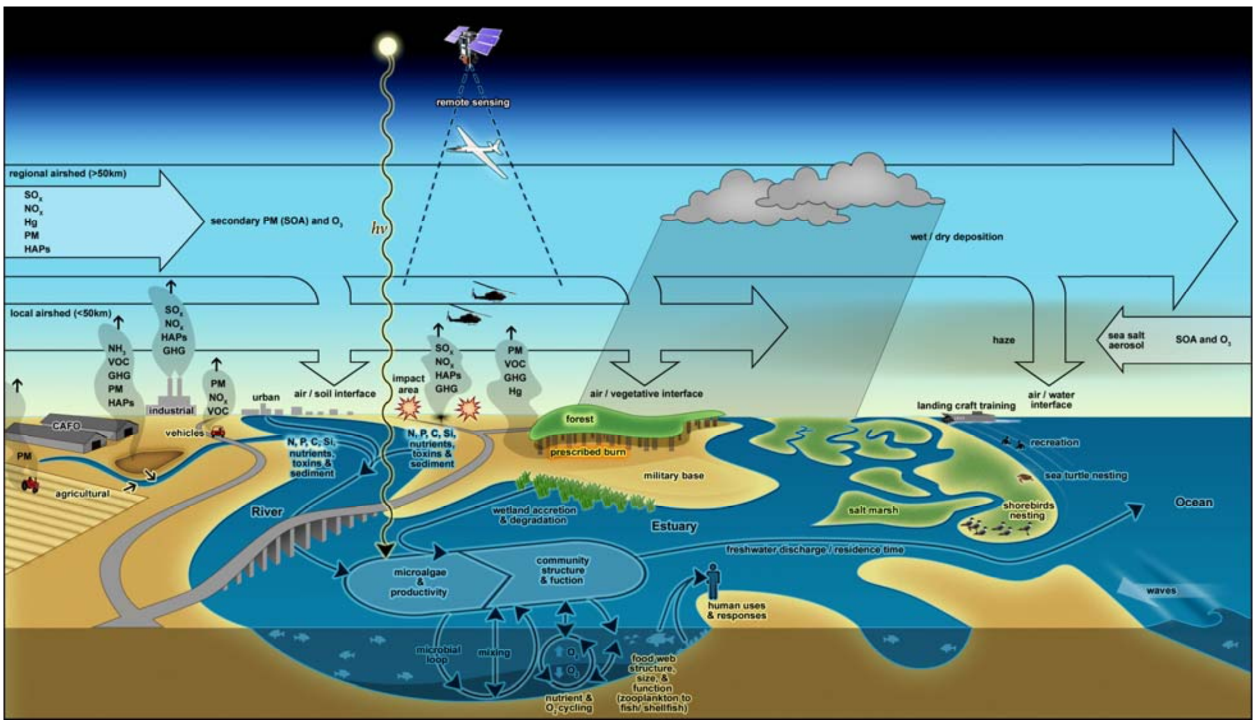


Figure ES-1. Overarching conceptual model for DCERP at MCBCL.

As an initial step in the planning effort, the overarching conceptual model was subdivided into four ecological modules: Aquatic/Estuarine Module, Coastal Wetlands Module (land-estuary margin), Coastal Barrier Module, and Terrestrial Module. These modules are linked to each other and to local and regional disturbances and pollutant sources of anthropogenic origin via atmospheric and aquatic transport mechanisms. Because the atmosphere has an overarching influence on all four ecosystem modules, it is treated as a fifth module (Atmospheric Module). A sixth module (Data Management Module) involves a

diverse group of specialists whose expertise will cut across all of the other modules to coordinate data management procedures for the DCERP data and information management system and will include coordination of geospatial data, statistical analysis, and model integration. The RTI DCERP Team will involves the participation of six module teams, one for each module, conducting monitoring and research activities under the direction of a Module Team Leader and Co-leader.

Integrated Ecosystem-based Management Approach

Early in Phase I of the program, the four ecological module teams and the Atmospheric Module Team developed individual conceptual models representing each ecosystem, identified knowledge gaps in the models, and determined the needs of MCBCL management. The module teams then determined potential research questions to fill these basic research gaps and to address MCBCL management needs. The DCERP Baseline Monitoring Plan is designed to gather environmental data to address MCBCL management concerns and to support the research projects identified in the Research Plan. During Phase II of the program, results from research projects will feed back into the adaptive DCERP Baseline Monitoring Plan so that changes in the frequency of sampling, spatial scale of sampling locations, or parameters to be sampled can be made as necessary. Results from the monitoring and research efforts will be used to identify ecosystem indicators and to develop associated threshold values, tools, or design models that address MCBCL management needs. Once this information is transitioned to MCBCL, the Base's natural resources managers will be able to make decisions about what type of management actions should be taken and then implement the appropriate actions. After implementing these actions, the RTI DCERP Team will continue monitoring (feedback loop) to ensure that the desired management outcomes are achieved. This planning and implementation process is shown in **Figure ES-2**.

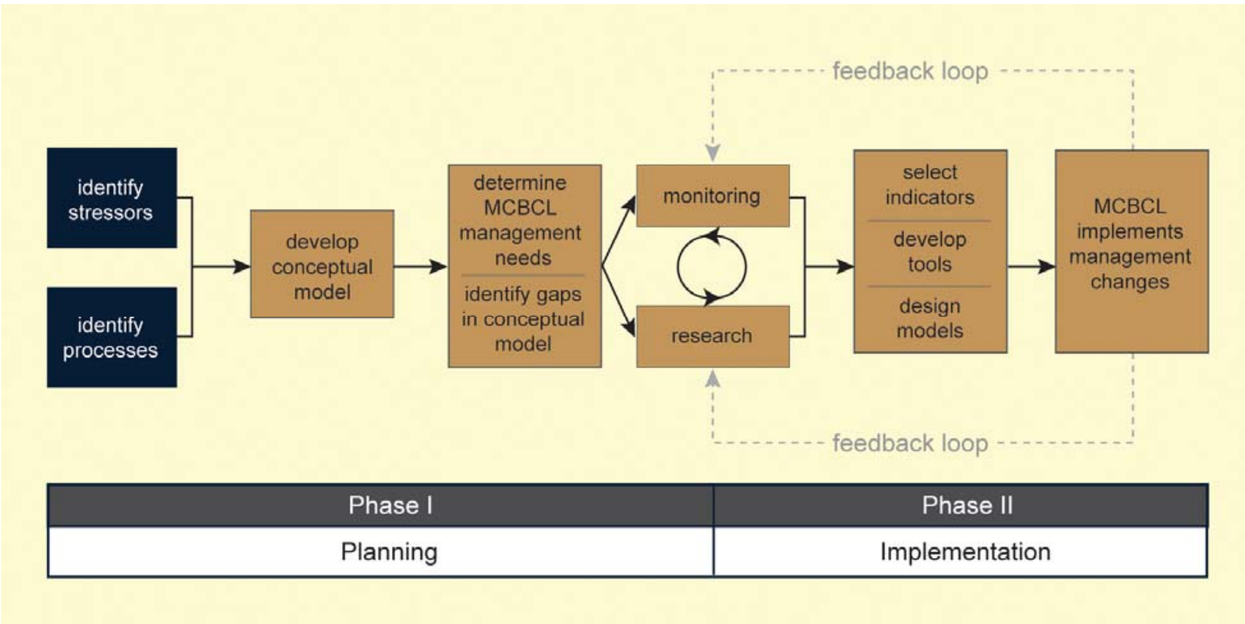


Figure ES-2. Planning and implementation process flowchart.

Research projects will incorporate appropriate data from the DCERP baseline monitoring program, MCBCL environmental monitoring activities, and other local, state, federal, and private monitoring activities to provide an integrated approach to ecosystem-based management and to alleviate redundancy of data collection. Schedules and site locations for research activities will be coordinated with the baseline monitoring program to ensure that linkages between the baseline monitoring sites and research projects are maintained. Results from research projects will feed back into the adaptive DCERP Baseline

Monitoring Plan so that changes in the frequency of sampling, spatial scale of sampling locations, or parameters being sampled can be made as necessary. In addition, knowledge gained from research can be incorporated into MCBCL's monitoring or form the basis for adaptive management.

DCERP Modules

This DCERP Strategic Plan provides an introduction to the five ecosystem modules and the Data Management Module designated for DCERP and describes the linkages of the various physical, chemical, and biological processes that occur among the modules. For each ecosystem module, the respective module team has developed a detailed conceptual model that is similar to the overarching conceptual model depicted in Figure ES-1. These individual conceptual models provide an overview of the key biological, chemical, and physical processes of the ecosystem, as well as the military, non-military, legacy, and natural ecosystem stressors that may affect the ecosystem.

Even with a basic knowledge of the processes and stressors affecting the system, there are knowledge gaps in each of the ecosystem conceptual models that need to be filled to improve the understanding of the respective ecosystems and their condition, state, and structure. This DCERP Strategic Plan discusses the key management objectives identified by the Base in several collaborative meetings with the RTI DCERP Team that are necessary in helping MCBCL meet its military mission. In addition, the individual ecosystem module subsections of this plan summarize of potential research questions that provide information to fill knowledge gaps and address Base management needs.

Specific Goals and Implementation Strategies

This DCERP Strategic Plan identifies the specific goals and implementation strategies that will be used to achieve the DCERP objectives. These goals include (1) designing and implementing a baseline monitoring program, (2) designing and conducting a research program, (3) creating a data repository, (4) developing tools for MCBCL managers to use to apply ecosystem-based adaptive management, and (5) preparing information for dissemination in different forms via various media to diverse groups of interested parties.

Baseline Monitoring Program

For the purposes of DCERP, baseline monitoring includes the monitoring of (1) basic (fundamental) parameters that support the broader research agenda, (2) parameters that provide data that are useful to more than one ecosystem module, (3) parameters that must be monitored for a minimum of 5–10 years, and (4) parameters that will likely be transitioned in a scaled-down form to MCBCL to monitor directly at the end of the DCERP efforts. The DCERP baseline monitoring program is described in detail in the DCERP Baseline Monitoring Plan and will accomplish the following:

- Quantitatively characterize levels and variations in key environmental drivers (ecological processes and stressors), including both natural and anthropogenic drivers, and the status of essential physical, chemical, and biological components of each ecosystem module (e.g., Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and Atmospheric)
- Integrate and synthesize the preceding measurements into an interdisciplinary understanding of the processes and stresses driving ecosystem dynamics and their impact on ecosystem components
- Incorporate a clear understanding and characterization of MCBCL operations, information needs, and specific management issues
- Identify clear monitoring objectives that respond to explicit management objectives or understanding of ecosystem functions and questions

- Based on the objectives, identify appropriate environmental variables that can be sampled and translated into indicators, metrics, and ecosystem performance standards
- Follow a hierarchical approach such that measurements of key variables are made on a variety of spatial and temporal scales to allow inferences in relationships between ecosystem components and organizing processes between scales and rigorous extrapolation and interpolation for cost efficiencies
- Include appropriate quality assurance/quality control (QA/QC) procedures
- Be designed to be transitioned into a long-term, Base-operated monitoring program that can be shown to adequately predict the status of the broader elements of the ecosystems monitored by DCERP
- Ensure a consistent approach to data collection for those environmental variables that could be subject to different data-collection methodologies and metrics
- Incorporate periodic assessment of all monitoring data that are collected to ensure that what is being collected remains relevant and to enable any needed adjustments to the Baseline Monitoring Plan.

Research Program

RTI DCERP Team has designed and will implement a research program that increases the knowledge base and understanding of MCBCL-relevant ecosystem functioning, stressors, and system responses to stresses and management actions. The overall research program is presented in the DCERP Research Plan and consists of 13 separate research projects that

- In combination, increase our understanding of overall ecosystem function for those ecosystems present at MCBCL
- Build upon an existing knowledge base, including previously conducted research by other scientists, collaborations with other ongoing MCBCL-funded research or monitoring efforts, and other projects funded by SERDP or separately funded programs
- Yield definitive results within a predefined time frame and budget
- Include focused studies designed to fill existing gaps in understanding of processes that may have critical influence on the status and dynamics of the ecosystems
- Produce explicit answers to management questions and challenges identified by MCBCL environmental managers
- Provide a durable legacy of the basic scientific understanding of MCBCL and other analogous ecosystems and of ecosystem-based management responses to stressors that could impact environmental sustainability.

Data Repository

The purpose of the DCERP data management and information system or “data repository” is to initially support the data management needs of DCERP and, ultimately, MCBCL’s long-term ecosystem-based data management needs by enabling cross-cutting modeling, statistics, and decision-support applications. The DCERP data and information management system consists of three distinct systems: the Monitoring and Research Data Information System (MARDIS) for structured data, a Document Database for unstructured data, and the DCERP Web sites (consisting of a public Web site and a private collaborative Web site). Data integration, data sharing, and data management will be key functions of the data management and information system. In addition, because the types and volumes of baseline data that currently exist and that will be collected through DCERP are extensive, the Data Management Module will standardize the input format of data across the other modules, such as date and time formats and standardization of measurement units for monitoring and research parameters.

Models, Tools, and Indicators

An ultimate goal of DCERP is to develop tools to enable MCBCL managers to identify adaptive, ecosystem-based management approaches. These tools will include models for forecasting the impacts of military activities and other stressors and indicators for assessing healthy, transitional, or degraded conditions. Planning for the future development and implementation of these end-user tools will require a focused planning and evaluation effort to identify and prioritize this work as DCERP evolves and matures. These efforts will be conducted in close coordination with the development of the DCERP data management and information system, and outcomes of these efforts will be used to refine the information system architecture of DCERP. Module teams might also develop modeling tools that integrate information from other modules to answer specific management objectives. These tools could provide a starting point for the development of a fully automated decision-support system.

Information Dissemination

The RTI DCERP Team members all have extensive experience in disseminating scientific and management information to a wide spectrum of audiences and through diverse communications media. During Phase II implementation, the RTI DCERP Team will provide semiannual reports and briefing updates (as desired) to MCBCL natural resources management staff. The reports will summarize the progress and results of monitoring and research in each module and facilitate feedback from MCBCL staff, thereby strengthening the link between DCERP Team researchers and the Base. The DCERP Collaborative Web site will be used to disseminate basic scientific and management-related papers produced as part of the program; guidance for ecosystem models developed for MCBCL; presentations created by DCERP Team members working on the program; and user-friendly tools for applying and displaying results of application of the ecosystem-based models to management issues, both on the Base and in analogous military installations.

Measures of Success/Outcomes

The successful implementation of DCERP will foster a greater understanding of the biologically diverse coastal barrier, coastal wetlands, aquatic/estuarine, and terrestrial ecosystems of MCBCL; the Base’s air quality; and the interactions of these systems with military training activities. This understanding will aid in the long-term management and sustainability of MCBCL ecosystems, which will enhance and maintain MCBCL’s military mission. Information and data resulting from the DCERP research and monitoring efforts will increase the ability of resource managers to perform assessments and implement appropriate management responses to potential environmental impacts arising from military activities or natural disturbance events. In addition, the DCERP monitoring metrics and techniques will likely be transferable to other DoD sites in ecologically similar settings.

Measurements of DCERP’s success will come from assessing whether the outcomes were achieved in a timely manner. The outcomes that have been defined for DCERP can be grouped into two main categories:

- Programmatic—Includes administrative requirements, such as delivering required documents on schedule and on budget, ensuring that the project Web site is developed and functioning, meeting SERDP quarterly and annual reporting requirements, and providing timely and effective feedback to MCBCL and outreach to stakeholders.
- Project specific—Includes those project-specific outcomes identified in the Research and Baseline Monitoring plans. In some cases, these outcomes provide information to address environmental issues that are currently impacting Base operations. Other research and monitoring efforts were designed to provide outcomes relevant to issues that are currently known and that are anticipated to impact Base operations in the next 3–5 years. In addition, the majority of DCERP research and monitoring activities will provide the information necessary to gain a complete

understanding of ecosystem functions, which will better prepare the Base to address future environmental issues.

Specific programmatic and project-specific overarching, strategic outcomes are included in this Strategic Plan. The project-specific outcomes associated with the individual research and monitoring efforts are provided in the DCERP Baseline Monitoring Plan and the DCERP Research Plan.

MCBCL has identified several high-priority, strategically important outcomes that they would like to result from DCERP. The design of the research and baseline monitoring programs has taken these into account and will seek to address each of the following outcomes (**Table ES-1**).

Table ES-1. MCBCL-Identified Strategically Important Outcomes

Outcome	DCERP Activities to Achieve Outcomes
Compliance with the Clean Water Act	Research and monitoring activities will provide data on water quality impacts resulting from local (Base activities) versus regional (outside of the Base) stressors, along with indicators and other thresholds of declining water quality.
Achieve no net loss of wetlands	Research and monitoring activities will identify wetland areas undergoing significant erosion; the relevant contribution of military activities to that erosion; and the management alternatives for mitigating wetland degradation.
Maintain the extent and ability to conduct military maneuvers on Onslow Beach	Research and monitoring activities will identify the underlying causes of accelerating beach erosion and provide the ability to project the rate of beach erosion that could result following the implementation of a variety of management actions.
Compliance with the Clean Air Act and National Ambient Air Quality Standards regulation and support the development of a Smoke Management Plan	Research and monitoring activities will quantify air emissions from the Base's prescribed burning program and provide the Base with the ability to forecast air emissions resulting from different management scenarios.

1.0 Introduction

Critical military training and testing on lands along the nation's coastal and estuarine shorelines are increasingly placed at risk because of development pressures in surrounding areas, impairments due to other anthropogenic disturbances, and increasing requirements for compliance with environmental regulations. The U.S. Department of Defense (DoD) intends to enhance and sustain its training and testing assets and to optimize its stewardship of natural resources through the development and application of an ecosystem-based management approach on DoD facilities. DoD policy has established ecosystem-based management as the preferred approach for military lands (Goodman, 1996). This management approach will focus on sustaining and enhancing military operations by monitoring and managing the interdependent natural resource assets on which the future of those operations depend. To expand its commitment to improving military readiness while demonstrating the science behind this approach, the Strategic Environmental Research and Development Program (SERDP) has made a long-term commitment of at least 10 years to fund research and monitoring projects that support the sustainability of military training and testing in ecologically and economically important ecosystems.

To accomplish the above goal, SERDP has launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina. (Note: DCERP is the second such program to use an ecosystem-based management approach – the first being the SERDP Ecosystem Management Project that has been ongoing at Fort Benning, GA, since December 1997). As a U.S. Marine Corps (USMC) installation, MCBCL has a single and exclusive mission: military preparedness. MCBCL provides an ideal platform for DCERP because it integrates coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems, all within the boundaries of DoD properties.

MCBCL was chosen as the DCERP site for a variety of reasons, including the following:

- The New River Estuary (NRE) watershed, which borders the site, is relatively small and, therefore, manageable
- MCBCL occupies a substantial portion (~80%) of the NRE shoreline
- A barrier island/coastal dune system occurs within MCBCL's boundary and provides a unique amphibious assault training environment
- The variety of ongoing military operations at MCBCL enables researchers to examine training impacts on a broad range of ecosystems, from upland pine savannas to aquatic/estuarine waters to coastal barriers.

Figure 1-1 provides a map of MCBCL in Onslow County, NC, and the surrounding watershed area.

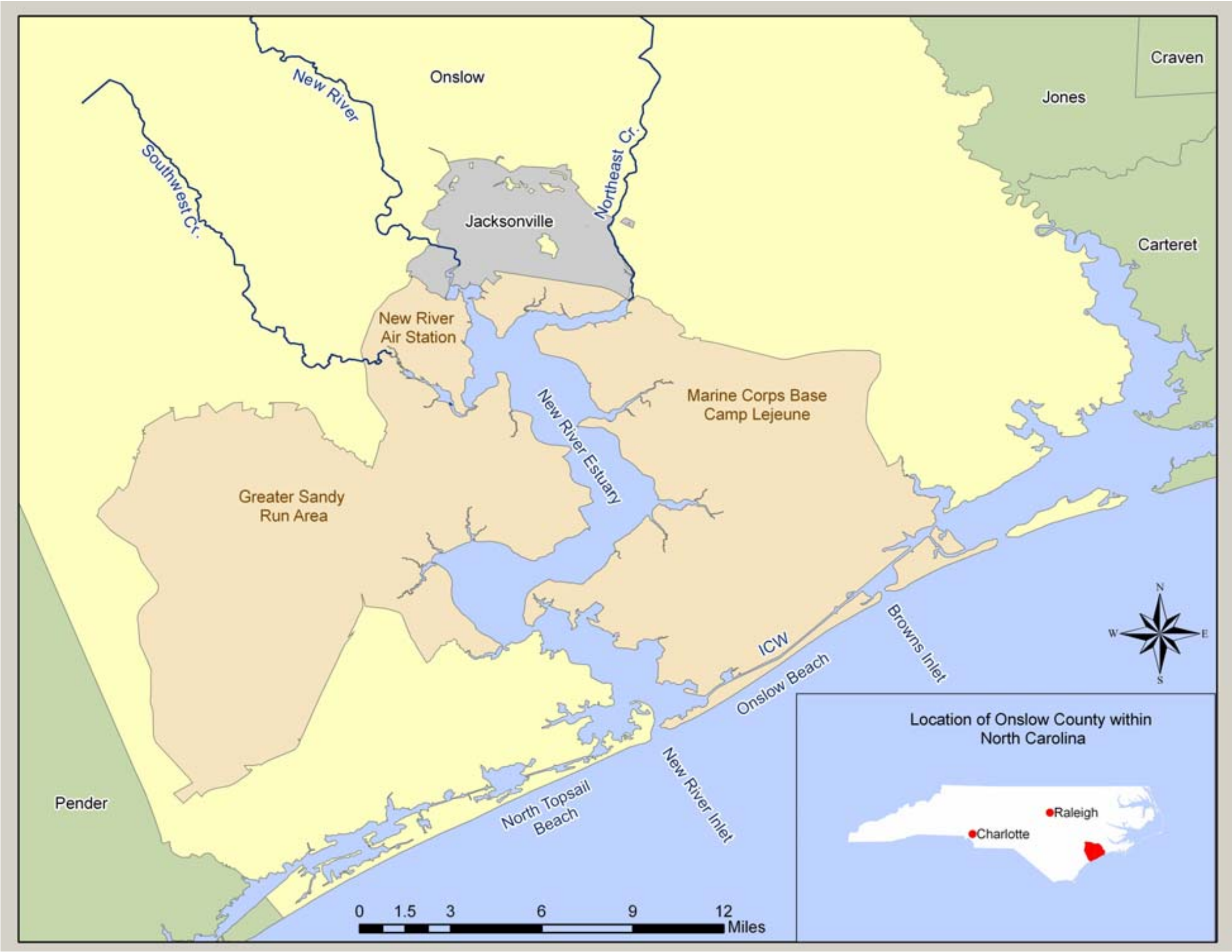


Figure 1-1. Site map of MCBCL.

As stated in the initial DCERP Strategy, "*The overall intent of the DCERP is to develop the knowledge required to assess the interaction between military activities and ecological resources in a coastal/estuarine setting, monitor those interactions, and identify adaptive, ecosystem management approaches for sustainment of military lands and adjacent waters*" (SERDP, 2005). DCERP is designed to provide relevant research and monitoring, develop and apply indicators, and provide MCBCL natural resource managers with assessment tools and criteria in support of ecosystem-based management.

RTI International (RTI), headquartered in Research Triangle Park, NC, is leading the DCERP research and monitoring effort. RTI has assembled a diverse team of experts in relevant disciplines of environmental science with many years of experience working together on interdisciplinary coastal, estuarine, and terrestrial ecosystem projects. The RTI DCERP Team will address the initial DCERP objectives of developing monitoring approaches and identifying key ecological processes through research and modeling studies, all with the goal of supporting the practice of ecosystem management for all coastal DoD installations in similar ecological settings.

DCERP is designed to be implemented in phases. Phase I of the program represents the planning period and includes the development of the overarching research strategy (*Defense Coastal/Estuarine Research Program Strategic Plan*, henceforth referred to as the DCERP Strategic Plan), design of an ecosystem-based monitoring program (*Defense Coastal/Estuarine Research Program Baseline Monitoring Plan*, henceforth referred to as the DCERP Baseline Monitoring Plan), identification of detailed research

projects (*Defense Coastal/Estuarine Research Program Research Plan*, henceforth referred to as the DCERP Research Plan), and development of a data repository design. Phase II of DCERP represents the program's implementation period and includes the execution of the DCERP Research Plan through field research; operation of the long-term ecosystem monitoring system; and collection, management, archiving, and analysis of data from both the research and monitoring components in the DCERP data repository or data and information management system.

2.0 Mission Statement

DCERP's mission is to conduct Base-relevant and basic and applied research in support of an ecosystem-based management approach. The result of the research will be an understanding of the composition, structure, and function of coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems as they relate to MCBCL's military mission.

3.0 Vision Statement

The DCERP vision is for MCBCL to ensure Base sustainability by managing military operations and activities using adaptive management based on a state-of-the-art monitoring and research program. SERDP envisions that the coastal, estuarine, wetland, and terrestrial ecosystems of MCBCL will possess sufficient generality to be applied to other DoD installations located along similar coastal and estuarine shorelines so that the sustainability benefits of DCERP will extend beyond the boundaries of this military installation.

To make this vision a reality, the RTI DCERP Team has developed an integrative, ecosystem-based approach that transcends air–land–water boundaries to study and understand the basis of ecological and environmental changes across the MCBCL region. The multidisciplinary design of this approach is intended to illuminate underlying system processes, identify stressor-specific indicators of important system changes, and specify critical thresholds that could threaten sustainability. From this understanding, adaptive, ecosystem-based models and management approaches can be identified for sustaining military operations in harmony with the important environmental assets of these military lands and adjacent waters.

4.0 Program Organization

DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering Service Center (NFESC), MCBCL, and the RTI DCERP Team. **Figure 4-1** illustrates the overall organization and lines of communication of the program.

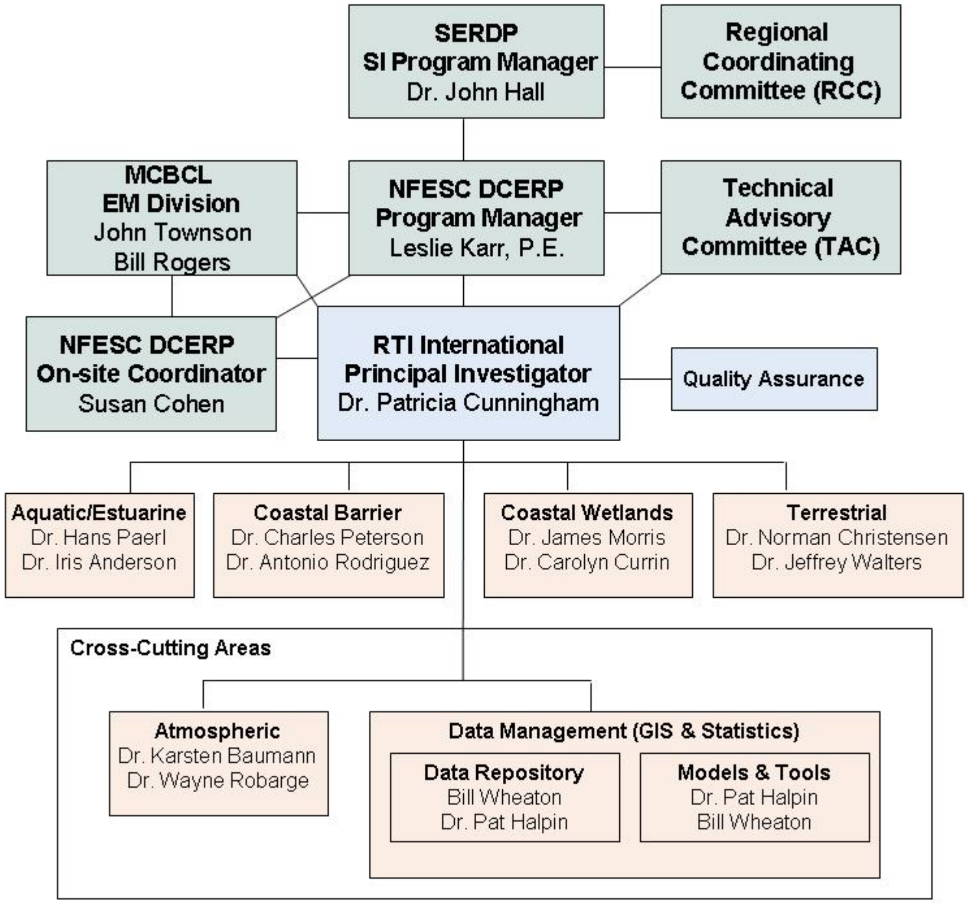


Figure 4-1. Organization of DCERP.

4.1 Management Team

SERDP is an environmental research and development program, planned and executed by the DoD in full partnership with the U.S. Department of Energy and the U.S. Environmental Protection Agency (EPA). The SERDP Sustainable Infrastructure Program Manager (PM), Dr. John Hall, ensures that DCERP activities provide for the enhanced knowledge of ecosystem and military interactions within approved scopes of work and budgets. The overarching federal management for DCERP was assigned to NFESC. The DCERP PM, Ms. Leslie Karr, is designated by NFESC and identifies the tasks and responsibilities of the RTI DCERP Principal Investigator (PI), Dr. Patricia Cunningham. As PI, Dr. Cunningham facilitates coordination of the RTI DCERP Team with MCBCL through the DCERP On-site Coordinator (OSC), Ms. Susan Cohen. At MCBCL, the DCERP OSC, the Director of the Environmental Management Division, Mr. John Townson, and the Head of the Environmental Conservation Branch, Mr. Bill Rogers, will assist the DCERP PM and DCERP PI with the coordination of environmental monitoring and research activities on the Base. The DCERP OSC is the primary point of contact between MCBCL and the RTI DCERP Team.

Two committees will provide guidance and input to DCERP. The first, the Technical Advisory Committee (TAC), is a group of discipline experts assembled by the DCERP PM to provide scientific and technical review to ensure the quality and relevance of DCERP. The TAC directs all questions and comments to the DCERP PM. The second committee, the Regional Coordinating Committee, is a group

of local and regional stakeholders that serves as one of the recipients of outreach from MCBCL, the DCERP PI, and the SERDP PM.

4.2 Research Team

The RTI DCERP Team includes the PI, other environmental scientists from RTI, and researchers from the University of North Carolina at Chapel Hill Institute of Marine Sciences, North Carolina State University, University of North Carolina at Wilmington, Duke University, Virginia Institute of Marine Sciences, Virginia Tech, University of South Carolina, National Oceanic and Atmospheric Administration (NOAA) (Center for Coastal Fisheries and Habitat Research, Beaufort, NC), U. S. Geological Survey (USGS) (Raleigh, NC, office), URS Corporation, and Porter Scientific, Incorporated.

The DCERP PI is responsible for the overall scientific quality, cohesiveness, and relevance of the DCERP Baseline Monitoring Plan and DCERP Research Plan. In addition, the DCERP PI is the primary point of contact for SERDP and MCBCL and coordinates all DCERP activities conducted at MCBCL through the DCERP OSC, Ms. Cohen. The RTI DCERP Team has been organized into six module teams based on the ecosystem-based management objective for the program. Each module team falls under the direction of a Module Team Leader and Co-leader. These module teams conduct monitoring and research activities for DCERP's five ecosystem modules (Aquatic/Estuarine Module, Coastal Barrier Module, Coastal Wetlands Module, Terrestrial Module, and Atmospheric Module) and Data Management Module. These modules will be described in further detail in Section 7, *DCERP Modules*, of this DCERP Strategic Plan.

4.3 Executive Board

The Executive Board for DCERP is composed of the DCERP PI and the Module Team Leaders and Co-leaders from each module team. The PI serves as Chairperson of the Executive Board. RTI provides a Secretary to the Executive Board to take meeting minutes, and these minutes are available to all members of the Executive Board. The Chairperson works with the Secretary to schedule and set the agenda for Executive Board meetings. The Chairperson also is responsible for ensuring that the Executive Board maintains reasonable consistency and integration in the overall project scope and direction. The Executive Board provides leadership and guidance on all technical and scientific aspects of the ecosystem modules to the PI, such as the following:

- Selection and scheduling of research projects to achieve the greatest benefit to the project and MCBCL
- Selection of baseline monitoring activities for inclusion into the overall DCERP Baseline Monitoring Plan that meets the needs of the module teams and provides a long-term historical record of basic environmental parameters
- Integration of monitoring/research activities for each module and the relationship of these activities to other module monitoring/research activities.

Although technical input is actively sought from the Executive Board, final decisions on program management and resource allocations to the various module teams is the responsibility of the Executive Board Chairperson.

5.0 Overarching Objectives and Goals

5.1 Overarching Objectives

DCERP's primary overarching objective is to enhance and sustain MCBCL's military mission by developing an understanding of coastal barrier, estuarine, coastal wetland, and terrestrial ecosystem composition, structure, and function within the context of a military training environment. Specific DCERP objectives include the following:

- Develop this DCERP Strategic Plan (overarching strategy) that includes appropriate conceptual and mechanistic ecosystem models to guide monitoring, research, and adaptive management
- Identify significant ecosystem stressors (military, non-military, legacy, and natural), their sources (on and off the Base), and their level of impact on MCBCL's ecological systems through space-time coordinated monitoring and research
- Incorporate stressor and other environmental information into ecosystem models to develop effective indicators of potential changes to ecosystem condition and state that may require more effective management guidelines to achieve sustainability.

To meet the DCERP objectives outlined above, the RTI DCERP Team will

- Ensure relevance of the program to MCBCL operations
- Ensure that outcomes reflect an adaptive management approach to ecosystem sustainability
- Develop and apply models that incorporate regional and local military drivers to support the sustainability or enhancement of military operations
- Use ecosystem-based models, including mission drivers, to identify methods and tools to support the sustainability or enhancement of ecosystem function and health
- Ensure implementation of essential monitoring, high-quality research, and data management procedures
- Conduct effective outreach and communication of information to the scientific community, MCBCL, and other military facilities, as well as other stakeholders and the general public.

5.2 Ecosystem-based Management Goals

The goals of the DCERP module teams are to achieve DCERP's overarching strategy: to enhance and sustain the military mission by creating sufficient understanding of the ecosystem structure, function, and dynamics to apply ecosystem-based management to sustain the natural resources and assets on which success of military training depends. In combination, the goals of the module teams comprise the technical information necessary to establish and implement an ecosystem-based management plan for the natural resource assets of MCBCL. DCERP has adapted the following elements of ecosystem-based management described by Christensen et al. (1996):

- ***Sustainability*** – The underlying premise is that military usability will persist indefinitely under a well-conceived ecosystem-based management plan.
- ***Explicit goals*** – Ecosystem-based management identifies specific measurable goals for which management is conducted and which can serve as indicators of success (See Section 8, *Specific Goals and Implementation Strategies*).
- ***Sound science and ecological models*** – The success of ecosystem-based management depends on the quality and completeness of the scientific understanding of the system and models that are required to synthesize information to make sound judgments.
- ***Complexity and connectedness*** – Ecosystem-based management recognizes explicitly that important interconnections exist among elements of an ecosystem and that these need to be understood to model the system properly and thereby provide tools to gauge the attainment of sustainability.
- ***Dynamic nature of ecosystems*** – Because of both extrinsic drivers and intrinsic interactions, components of ecosystems are not static, and this natural variability must be understood to detect signals from other stressors and to set realistic management goals.
- ***Context and scale*** – Ecosystems are driven by processes at multiple scales in space and time, and recognizing the regional setting of these processes is critical for modeling locally driven impacts.

- ***Humans as ecosystem components*** – Rather than ignoring humans, ecosystem-based management explicitly places humans in the system as one important element that can play an active role in achieving sustainable management goals.
- ***Adaptability and accountability*** – Ecosystem-based management realizes that existing models are always incomplete and predictions uncertain; therefore, management actions need to be treated as hypotheses and tested as a practical means of ensuring success and providing feedback to improve the models.

6.0 Overarching Research Strategy

The RTI DCERP Team has designed an integrative monitoring, modeling, and research strategy for MCBCL that is consistent with guidance on ecosystem-based management from the Ecological Society of America (Christensen et al., 1996) and recent recommendations of the United States Commission on Ocean Policy (2004), including principles of adaptive management (Walters, 2001). This strategy transcends air-land-water boundaries to better understand the causes and nature of ecological and environmental change across the region, as well as locally at MCBCL. Based on interconnectivity, this strategy helps separate the underlying natural (e.g., climatic or biogenic) and anthropogenic-regional processes from locally driven processes; identifies stressor-specific indicators of ecosystem status that provide early warnings of ecosystem degradation; and specifies critical thresholds for indicators of potential state shifts that could threaten sustainability. A threshold is a point at which further degradation in ecosystem condition will result in the system's inability to return to its initial state without significant intervention (SERDP, 2005). The biological, chemical, geological, and physical processes associated with each ecosystem are summarized in scientifically rigorous conceptual models; these models incorporate an understanding of the dynamic processes that interconnect ecosystem components in often complex ways. **Figure 6-1** presents the overarching conceptual model for the MCBCL region, which includes the terrestrial lands of MCBCL, the NRE, associated coastal wetlands, and the coastal barriers along Onslow Bay, as well as the overarching influence of atmospheric conditions.

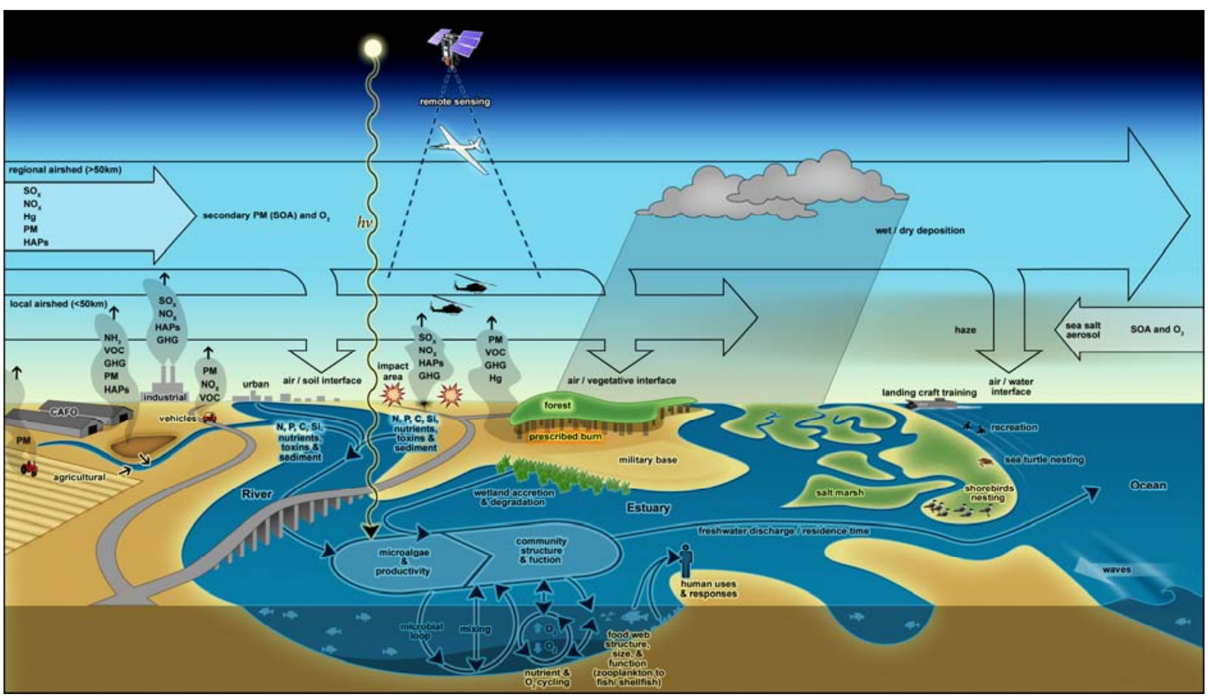


Figure 6-1. Overarching conceptual model for DCERP at MCBCL.

To facilitate an understanding of the ecosystem state and dynamics of the MCBCL region, the overarching conceptual model was subdivided into four ecological modules for monitoring, modeling, and research: the Aquatic/Estuarine Module, Coastal Wetlands Module (land-estuary margin), Coastal Barrier Module, and Terrestrial Module. These modules are linked to each other and to local and regional disturbances and pollutant sources of anthropogenic origin via atmospheric and aquatic transport mechanisms. Because the atmosphere has an overarching influence on all four ecosystem modules, it is treated as a fifth ecosystem module (Atmospheric Module). Individual conceptual models for each of the five ecosystem modules are presented in Section 7 (*DCERP Modules*).

The individual ecosystem modules are linked to each other to differing degrees. The Terrestrial Module is affected by regional atmospheric deposition and produces atmospheric releases, such as smoke produced during wildfires or prescribed burns. Activities on land, release materials for transport by air, surface, and groundwater flows, and these materials affect the ecology of wetland, estuarine, and coastal habitats. The Coastal Wetlands Module studies brackish and saltwater marshes and adjacent intertidal habitats that act as buffers to retain and process nutrients and other pollutants and as filters to trap sediments and pathogens in stormwater runoff so that these pollutants do not contaminate the estuary. Coastal wetlands also provide important nursery habitat to fishery organisms, which as juveniles move with the tide between marsh and tidal creek habitats, and as adults, link intertidal, estuarine and coastal habitats. The Aquatic/Estuarine Module studies how the NRE processes sediments and other pollutants and transforms nutrients into microalgal and higher plant biomass that support the food web, including the NRE's critically important fisheries' resources that are inextricably linked to nearshore and coastal ocean habitats. The Coastal Barrier Module has water habitat at both boundaries; wetland and shoreline habitat at both land margins; and terrestrial dune, shrub, and forest habitat in the center. The degree of storm damage from waves and high water to the region's wetland and shoreline habitats depends on the physical integrity of the coastal barrier. In the absence of a healthy, functioning coastal barrier ecosystem, physical forcing from ocean waves and tides could negatively affect and permanently alter the function of the estuarine, aquatic, and terrestrial systems.

The ecosystem-based management strategy will focus on the joint sustainability of military activities and fundamental ecosystem functions and services. This strategy will be designed around specific, quantifiable goals related to the status of resources (e.g., training and testing areas) that are central to the military mission of MCBCL. Assessments of how to manage military activities in ways that sustain the value of natural ecosystem assets, as well as management recommendations, will be regularly delivered to MCBCL natural resources managers. In addition, these assessments will be integrated into the ecological conceptual models, biogeochemical syntheses, and environmental and geographic information systems (GIS) databases that will be perpetuated as a legacy of MCBCL's commitment to environmental sustainability.

A sixth module, the Data Management Module, involves a diverse group of specialists whose expertise will cut across all of the other modules to coordinate data management procedures for the DCERP data and information management system, including coordination of geospatial data, statistical analysis, and model integration. The Data Management Module involves both a database component and a models and tools component. The models and tools component provides the ultimate cross-cutting function of integrating the simple models, developed in the individual research projects, into integrated management models. SERDP conceived the database (or "data repository") component as being developed to facilitate the collection and storage of environmental data collected by the RTI DCERP Team, as well as to be the permanent repository for research and monitoring data collected during DCERP's implementation.

During the first few years of the program, the RTI DCERP Team will develop models and management tools that reflect advances in GIS and spatial and time-series modeling and biological, chemical, and physical processes. This development will be supported by resources allocated to the individual modules.

In later years, however, development of calibrated, tested, and operational management models will be proposed for funding as part of the Data Management Module. Management models need to be usable by natural resources and watershed managers and fully tested so they are of known reliability; therefore, these models will be archived in the DCERP data and information management system for development and final calibration and testing before being made available to MCBCL.

6.1 MCBCL's Natural Resources Management

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces, and all natural resources management activities on the Base must support this mission. As a military installation, MCBCL has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, MCBCL must comply with related environmental laws and regulations, such as the federal Endangered Species Act (ESA) and Clean Water Act (CWA), to ensure continuance of the military mission. A summary of these federal and state regulations is provided in **Appendix A**. To ensure such compliance, MCBCL has adopted an *Integrated Natural Resources Management Plan* (INRMP) (MCBCL, 2006a), which outlines the Base's conservation efforts and establishes procedures for fiscal years 2007 through 2011. One goal of the INRMP is to minimize future training restrictions (i.e., no net loss in the ability to train) by increasing integration between natural resources management planning, training, and operations. It is the goal of DCERP to assist MCBCL in achieving this goal.

Unique to MCBCL are installation-specific drivers that are defined by the Base's mission and geographic location, land uses to support the mission, and natural resources affected by the mission. Identification of the primary military drivers at the Base provided the basis for establishing six natural resources management objectives for MCBCL's INRMP (MCBCL, 2006a). These six natural resources management objectives are the following:

1. Preserve the integrity of the amphibious maneuver areas, including Onslow Bay, the NRE, and the adjoining training areas and airspace of MCBCL.
2. Preserve the integrity of MCBCL as a combined-arms training base by ensuring the continued viability of its impact areas and associated training ranges.
3. Enhance future training uses of MCBCL ranges, training areas, and airspace by fully integrating the *Land Use Master Plan* (MCBCL, 2005) and *Range Transformation Plan* (MCBCL, 2006b).
4. Ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.
5. Ensure that MCBCL supports continued military training use of the New River, the NRE, and Onslow Bay by complying with the CWA.
6. Ensure the viability of the USMC New River Air Station as an aviation facility through the elimination of bird and wildlife strike hazards to aircraft while complying with the ESA and other wildlife regulatory requirements.

In addition to these military drivers, MCBCL natural resources staff have identified a prioritized list of conservation and water quality needs that will support implementation of the INRMP. **Appendix B** illustrates the Base's needs and identifies the DCERP approach for addressing these needs. As part of DCERP, every effort will be made to address areas of concern (AOCs) that are not currently being investigated or improve upon existing programs that are attempting to address these AOCs.

6.2 Conceptual Model Development

Each of the five ecosystem modules has developed a conceptual model. These models were developed to include the key biological, chemical, and physical processes of the ecosystem, as well as the military, non-military, legacy, and natural ecosystem stressors that may affect the model (**Figure 6-2**).

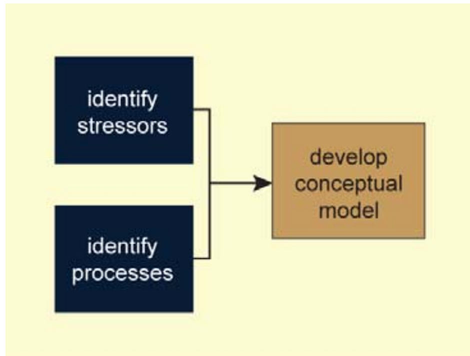


Figure 6-2. Development of the Conceptual Model.

The focus of the DCERP monitoring and research effort includes biological processes (e.g., primary production and respiration), chemical processes (e.g., water column and sediment nutrient processing/cycling and atmospheric transformations), and physical processes (e.g., hydrodynamics of the NRE and sediment transport along Onslow Beach), which are described in the individual module narratives**.** These key biological, chemical, and physical processes are the driving forces of the function of the ecosystem in the absence of stressors. Although the main processes are generally understood, the biological, chemical, and physical ecosystem processes at MCBCL have not been researched extensively, especially within the context of outside stressors. For DCERP, stressors are defined as activities or events that alter natural ecological processes. The RTI DCERP Team has grouped stressors into four major categories: military, non-military, legacy, and natural. **Table 6-1** provides a definition for each category, as well as specific examples relevant to DCERP. The conceptual models developed for each module were designed to integrate the ecological processes and stressors with the Base's military drivers and conservation and water quality needs, as determined by MCBCL for management of natural resources. The key military drivers and natural resources management needs are listed in Section 6.1, *MCBCL's Natural Resources Management*, of this report. For more information on these drivers, refer to MCBCL's INRMP (MCBCL, 2006a).

Table 6-1. Examples of Military, Non-Military, Legacy, and Natural Ecosystem Stressors

Stressor	Examples
Military	Military stressors are unique activities or events associated with military training and testing at MCBCL, including the use of military tracked vehicles and amphibious watercraft or boats, troop movements on the Base, and the use of firing ranges and impact areas. For example, direct effects of military activities on the NRE include the resuspension of bottom sediments in shallow water areas or physical damage to benthic communities when training boats are launched. In addition, indirect effects of military activities may include erosional runoff from training areas where vehicles and troops have compacted or otherwise disturbed the soil surfaces and bank erosion due to the movement of amphibious watercraft near splash points.
Non-military	Non-military stressors include any anthropogenic activities that can occur on Base or off Base, including runoff of nutrients from confined animal feeding operations (CAFOs), agricultural practices, or urban lands; discharges from industrial facilities and municipal wastewater treatment plants (WWTPs); runoff of land-applied sewage sludge; atmospheric deposition of nutrients and contaminants; groundwater withdrawals; local residential or commercial development; emissions from non-military vehicles; PB activities; and commercial and recreational fishing.

Stressor	Examples
Legacy	Legacy stressors are anthropogenic activities that have occurred in the past whose effects are continuing today. Examples include the construction of the Intracoastal Waterway (ICW), early ditching activities to drain land, historic use of fire, agricultural activities, timber harvesting, and discharges of nutrients by the City of Jacksonville WWTP (this discharge was eliminated in 2000).
Natural	Natural stressors include natural forces (e.g., hurricanes and sea-level rise) whose effects are enhanced by anthropogenic activity (e.g., global warming). The increased frequency and intensity of natural events, in combination with anthropogenic contributions, could cause ecosystem perturbations outside the range of natural variation.

6.3 Integrated Ecosystem-based Management Approach

Figure 6-3 illustrates the overall process that will be used to meet the DCERP objectives. After developing the individual conceptual models in Phase I, DCERP module teams identified knowledge gaps in the models and determined the needs of MCBCL management. The module teams then determined potential research questions to fill these basic knowledge gaps and to address MCBCL management needs. DCERP is a research-initiated process that is distinct from other ecosystem-based programs that are driven by specific regulatory or management objectives. The DCERP Baseline Monitoring Plan is designed to gather environmental data to address MCBCL management concerns and to support the research projects identified in the DCERP Research Plan. During Phase II, results from research projects will feed back into the adaptive DCERP Baseline Monitoring Plan so that changes in the frequency of sampling, spatial scale of sampling locations, or parameters to be sampled can be adapted as necessary. Results from the monitoring and research efforts will be used to identify ecosystem indicators and develop associated threshold values, tools, or design models that address MCBCL management needs. This information will be communicated to MCBCL to assist in the decision process. This information transfer may occur rapidly for some management needs or may require longer periods for the collection of research and monitoring data to provide appropriate indicators, models, or other tools. Once this information is transitioned to MCBCL, the Base’s natural resources managers will be able to make decisions as to what type of management action should be taken and implement appropriate physical or military operational changes. After the implementation of these changes, the RTI DCERP Team will continue monitoring (feedback loop) to ensure that the desired management outcomes are achieved.

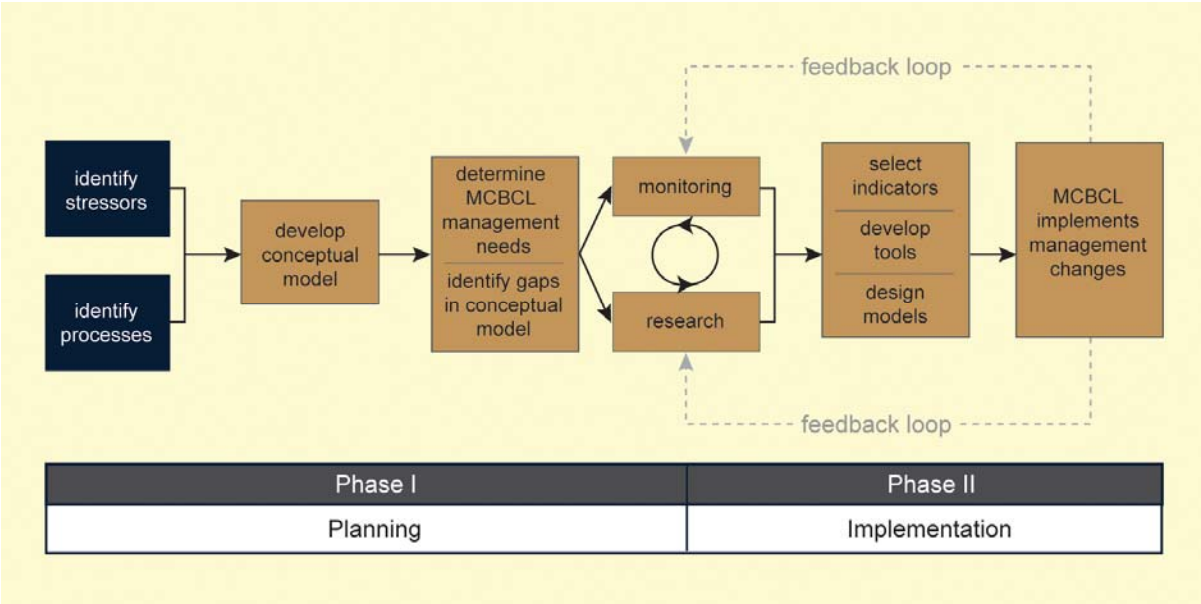


Figure 6-3. Overall DCERP approach.

This DCERP Strategic Plan provides the key foundation for the development of DCERP's Baseline Monitoring Plan and Research Plan. The RTI DCERP Team developed these plans based on the detailed information presented in each ecosystem module's conceptual model. Discussions of each of the five ecosystem conceptual models and the Data Management Module are presented in Section 7, *DCERP Modules*. The specific goals and implementation strategies for DCERP are described in Section 8, *Specific Goals and Implementation Strategies.* Finally, Section 9, *Measurements of Success,* provides the measures that can be used as indicators of the successful implementation of DCERP and the achievement of program outcomes.

7.0 DCERP Modules

This section of the DCERP Strategic Plan provides an introduction to the five ecosystem modules and the Data Management Module designated for DCERP. The key physical, chemical, and biological processes inherent in each ecosystem and the associated stressors (military, non-military, legacy, and natural) that affect these processes are discussed in detail and shown graphically in the individual ecosystem conceptual models. Linkages of the various physical, chemical, and biological processes that occur among the modules are also described. Even with a basic knowledge of the processes and stressors affecting the system, there are knowledge gaps in each of the ecosystem conceptual models that need to be filled to improve the understanding of the respective ecosystems and their condition, state, and structure. Key management objectives identified by the Base in several collaborative meetings with the RTI DCERP team are identified as necessary in helping MCBCL meet its military mission. Lastly, each ecosystem module subsection summarizes a list of potential research questions that provide information to fill knowledge gaps and address Base management needs; however, DCERP is not designed to answer all of these questions.

7.1 Aquatic/Estuarine Module

Introduction

Estuaries integrate inputs from terrestrial, freshwater, oceanic, and atmospheric systems (Day and Kemp, 1989; Valiela et al., 1997; Hobbie, 2000), and the accurate assessment and management of estuaries necessitates consideration of their connections to, and interactions with, these other systems. Estuaries also exist in regions of rapidly expanding and diversifying human activity (Nixon, 1995; Boesch et al., 2001; Cloern, 2001). In the context of the MCBCL region, the Aquatic/Estuarine Module will examine the tidal reach of the NRE from the freshwater head of the New River near Jacksonville, NC, to the tidal inlet at Onslow Bay (see **Figure 1-1**). Understanding and sustaining the function of the NRE cannot occur without quantifying and distinguishing natural processes from human-influenced watershed- and airshed-based impacts, as well as human activities that occur in the estuary (Nixon, 1995; Paerl, 1997; Malone et al., 1999; Boesch et al., 2001).

Key Physical, Chemical, and Biological Processes

Estuarine responses to physical, chemical, and biological processes may serve as indicators of ecological change (National Research Council, 2000; Cloern, 2001; Peierls et al., 2003; Neimi et al., 2004). Inputs of nutrients, sediments, organic matter, and contaminants reach the NRE from multiple sources, including watershed inputs, low-tide rainfall erosion of the salt marsh, wet and dry deposition from the atmosphere, and tidal exchanges with Onslow Bay. Watershed inputs include sources from the New River upstream from Jacksonville, NC; creeks that drain into the NRE; surface runoff; and groundwater as baseflow. These inputs influence the biological and chemical cycling within the NRE's water column and sediments (e.g., nutrient cycling and sediment transport) (Cloern, 2001; Anderson et al., 2003). Nutrients stimulate both phytoplankton and benthic microalgae (primary production), thereby providing food for zooplankton and benthic invertebrates (secondary production), respectively (Hobbie, 2000; Sundbäck et al., 2003). The zooplankton and benthic invertebrates provide food for fish, and phytoplankton is the primary food source

for shellfish. An overgrowth of phytoplankton and excessive sediment inputs from the main river and smaller tributaries, however, can reduce light penetration, leading to declines in important benthic and nursery area attributes, such as submerged aquatic vegetation (SAV) and benthic microalgal abundance (Gallegos et al., 2005), thereby reducing the food supply for benthic-feeding fish and interfering with the role of benthic microalgae in moderating water column nutrient enrichment. Additionally, excessive amounts of phytoplankton (e.g., algal blooms) sink from surface to bottom waters within the estuary and, together with watershed inputs of organic matter, lead to depleted oxygen conditions (e.g., hypoxia or anoxia) in bottom waters. Such hypoxic and anoxic events can have critical negative impacts on shellfish, other invertebrates, and finfish (Paerl et al., 1998; Rabalais and Turner, 2001). These processes may be influenced by water exchanges with Onslow Bay, which have the potential to remove excess nutrients, organic matter, and phytoplankton. The NRE's response to natural and anthropogenic impacts depends in part on physical and biological interactions, such as wave activity that leads to the resuspension of bottom sediments and freshwater discharge and exchange that affects the estuary's water residence time and degree of stratification (Luettich et al., 2000). These conditions strongly influence the biomass and composition of the autotrophic communities within the NRE, the estuary's susceptibility to hypoxia/anoxia, and the relative importance of microbial processes that may remove nutrients from both the water column and benthos. **Figure 7-1** presents the conceptual model for the Aquatic/Estuarine Module, illustrating the complementary nature of these critical estuarine physical, chemical, and biotic processes and interactions.

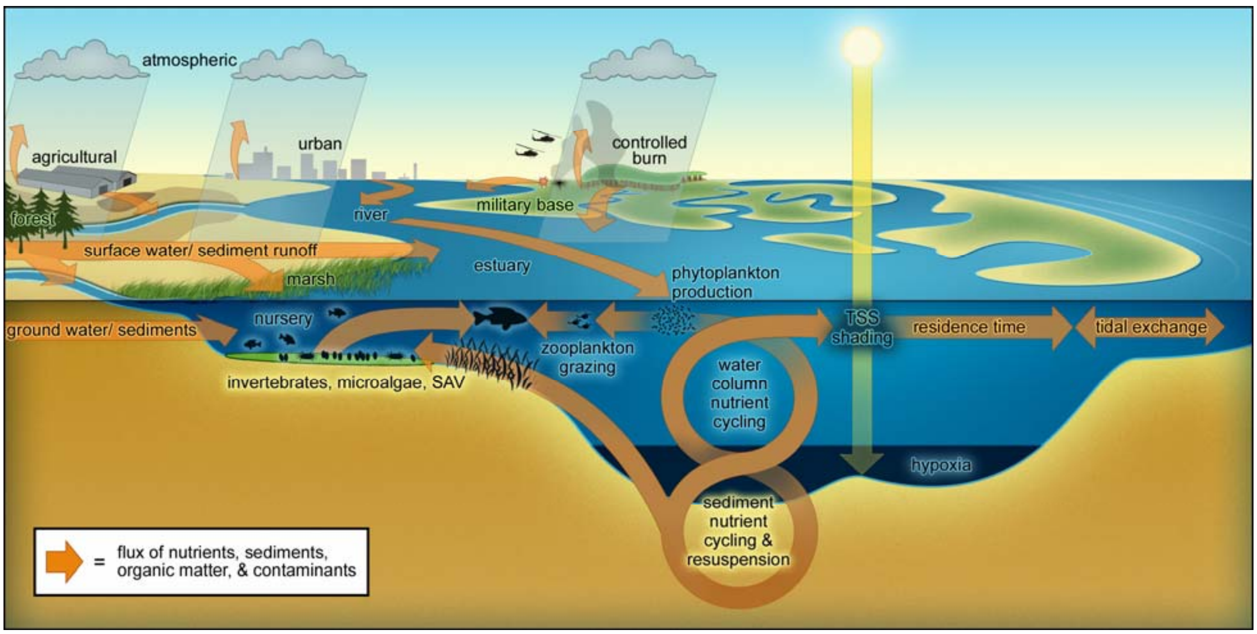


Figure 7-1. Conceptual model for the Aquatic/Estuarine Module.

Stressors

Military and non-military stressors, in combination with natural and anthropogenic legacy stressors, can alter the ecological processes controlling the productivity, biotic integrity, and sustainability of the NRE.

Military. Military training and testing activities at MCBCL have both direct and indirect impacts on the NRE. Direct effects on the NRE include the resuspension of bottom sediments and tidal creek bank erosion due to the operation of military watercraft in shallow water areas or physical disturbances to benthic communities when training boats are launched at designated splash points. Other effects of military activities are indirect and include runoff from training areas; increased erosion from all vehicles, especially tracked vehicles that have compacted or otherwise disturbed the soil surfaces; and erosion or

runoff into the estuary because of the use of troops or vehicles. MCBCL land surface is also disturbed by military range testing of munitions and other explosives, which can cause craters on the soil surface or start localized wildfires from incendiary materials in the ordnance in impact areas. In addition, the degradation of ordnance and casing materials can also reach the NRE indirectly through runoff or the leaching of these materials into soils through near-surface groundwater circulation.

Non-Military. Non-military stressors affecting the NRE include runoff or the leaching of nutrients from CAFOs, discharges from WWTPs, runoff of land-applied sewage sludge and other fertilizers, atmospheric deposition of nutrients and contaminants, groundwater withdrawals, local development around NRE tributaries, PB activities, and commercial and recreational fishing pressures (Mallin et al., 2005). The impacts of these stressors can be strongly modulated by climatic events, such as droughts, tropical storms, and hurricanes (Paerl et al., 2001; Peierls et al., 2003; Paerl et al., 2006). The amount and timing of watershed and groundwater (baseflow) inputs are dependent on the distribution of land use in the NRE watershed, primarily the amount of forest, agriculture, and urban development. Increasing development on MCBCL and in surrounding coastal areas increases the quantity of runoff and may decrease the quality of water flowing into the estuary through the addition of nutrients, sediments, and other contaminants. Although adequate nutrient supplies are necessary to support primary production, excessive supplies may result in eutrophication, harmful algal blooms (HABs), hypoxic/anoxic events, and fish kills (Nixon, 1995; Paerl et al., 1998). Suspended sediments also impact primary production by controlling light availability to phytoplankton in the water column, as well as to benthic microalgae, macroalgae, and seagrasses in bottom waters (Gallegos et al., 2005). Excessive sediment loading can also have detrimental effects on benthic invertebrates and shellfish communities through smothering. Contaminants, whether in dissolved form or as particulates such as pathogens, may influence all biotic components within an estuary, including humans. Water quality within an estuary is greatly influenced by coupling between the water column and benthos (Anderson et al., 2003). This is especially true in shallow systems such as the NRE, where primary production in the benthos removes and retains nutrients, which can reduce the system’s vulnerability to eutrophication. However, major climatic events can cause sediment resuspension, which can keep materials in flux between the water column and sediments.

Legacy. An example of a legacy stressor in the NRE is the previous discharge of nutrients from Jacksonville, NC, and the MCBCL WWTP (this discharge was eliminated in 2000 with the construction of a new treatment plant) and from inadvertent spills of sewage and animal waste following large hurricanes (Mallin et al., 2005). These activities and events have contributed large quantities of nutrients and other contaminants that are sequestered in bottom sediments. The presence of these historic, as well as current perturbations could have catastrophic consequences during future storm events, resulting in the resuspension of sediment and its associated nutrients and contaminants.

Natural. The NRE is located in a region that experiences frequent meteorological extremes. Tropical storms and significant deviations from typical precipitation patterns have recently been the rule rather than the exception in coastal North Carolina. Climatic events and hydrodynamics strongly influence the processing and effects of nutrients derived from both land and sea (Peierls et al., 2003; Paerl et al., 2006). For example, storm and rainfall events have the potential to dramatically influence residence time within the NRE, which can determine the effectiveness of microbial processes in the removal of nitrogen and the composition of the algal community (including HABs). In addition, the strength and duration of water column stratification will likely determine the susceptibility of the NRE to hypoxic/anoxic events. The increased frequency and intensity of natural events, in combination with anthropogenic contributions, could cause ecosystem perturbations outside the range of natural variation.

Linkages to Other Modules

Because of the central role the NRE plays in MCBCL and regional ecosystem processes, the Aquatic/Estuarine Module will be closely and extensively linked to all other modules (see **Figure 7-1**). Watershed characterization from the Terrestrial Module will be linked to tributary monitoring to provide information about the effects of land use on watershed exports of materials (Valiela et al., 1997; Alexander et al., 2000; Dai et al., 2000; Brush et al., 2002). Measurements of benthic production and watershed sediment loading will be linked to fish and marsh accretion studies in the Coastal Wetlands Module, and the Coastal Wetlands Module's assessments of nutrient processing at the land-water margin will be incorporated into the watershed modeling of nutrient and sediment loading. The input for atmospheric nitrogen to the NRE, determined by the Atmospheric Module, will be critical for assessing the response of estuaries to nutrients in sediments and the water column. Because coastal waters can be either a source or a sink for the NRE, data from the Coastal Barrier Module will supply the required information on estuarine-shelf exchanges of water and materials. The linkages outlined above are representative examples of the nearly infinite connections of the NRE to its local and regional surroundings.

Knowledge Gaps in the Conceptual Model

Conducting research to fill knowledge gaps in the understanding of the Aquatic/Estuarine conceptual model can improve the fundamental understanding of the NRE and the ability to forecast changes that may result from various stressors. Unlike many other ecosystems, the estuarine dynamics of the NRE have not been comprehensively described in a fashion that permits extensive cross-system generalizations. The work of the Aquatic/Estuarine Module Team will begin with efforts to improve the understanding of the NRE's ecosystem processes and to develop diagnostic tools and indicators to assess estuarine function, especially responses to diverse anthropogenic and natural stressors.

Identifying and distinguishing the effects of local versus regional stressors and their ecological impacts in the NRE are key research needs. In addition, determining the impacts resulting from long- and short-term stressors and stressors occurring at different times (e.g., legacy versus current stressors) is a priority for this system. Obtaining quantitative information on the loadings of nutrients, sediment, and pathogens from the watershed and understanding the transformation of nutrients that occurs within the NRE are two research priorities for the Aquatic/Estuarine conceptual model. There is a need to identify high-priority stressors and locations affected within the ecosystem context. Identification and development of appropriate indicators of productivity and community structure for the NRE and studies of stressor-specific responses (e.g., algal blooms, hypoxia, and food web perturbations) are also needed. In addition, an understanding of biotic integrity relative to local and regional stressors and in support of primary nursery area (PNAs) and key ecosystem functions is lacking.

The hydrodynamics of the NRE are influenced by the freshwater watershed inputs and baseflow from groundwater, as well as by tidal saltwater exchanges through Onslow Bay. Studying the factors that modulate the residence time for this estuary and the role of physical processes involved in loading, transformation, exchange and fate of nutrients, sediments, pathogens, and other contaminants are of paramount importance to understanding ecosystem-based management options for the NRE. Water quality within shallow water estuaries such as the NRE is influenced by coupling between the water column and the benthos. Water column and sediment interactions and their impacts on nutrient cycling, productivity, water quality, and food web dynamics (e.g., benthic-pelagic coupling) need to be examined and assessed within this system.

Key Management Objectives

The key MCBCL management objective for the Aquatic/Estuarine Module is to ensure the continued water quality, ecological functions, and biological integrity of the NRE, as mandated by the CWA. Tasks

for this objective include managing water and land resources to avoid the imposition of Total Maximum Daily Loads (TMDLs) and maintaining National Pollutant Discharge Elimination System permits. MCBCL must meet this mandate while sustaining and enhancing military training opportunities. Specific MCBCL needs relating to the NRE include the assessment of non-point source pollution, stormwater runoff, HAB and hypoxia potentials, planktonic and benthic biotic integrity, and PNAs. The Base must effectively manage the NRE within the context of both natural and anthropogenic stressors. One challenge to satisfying the key management objective is the predicted elevated storm activity for the region. The increased number of storms, as well as the possibility of more intense storms (Paerl, 2005; Paerl et al., 2006a; Paerl et al., 2006b; Paerl et al., 2006c), will present challenges for the program because of the potential magnitude of changes to the physical structure and function of the NRE ecosystems, as well as the impact on human development, which may be severely affected by these storms. Like all stakeholders in coastal waters, MCBCL has responsibilities for the NRE, which has been designated as nutrient-sensitive by the North Carolina Department of Environment and Natural Resources. MCBCL also has responsibility for meeting stakeholder water quality requirements to support recreational and commercial uses of the NRE system. The Aquatic/Estuarine Module will provide data and decision-support tools to enhance MCBCL's ability to reach its water quality management goal.

Research Questions

Because of the complexity of estuarine drivers and the need for decision-support tools for the management of the NRE, it is necessary to develop easily applied indicators of ecosystem condition and simulation models to forecast changes in the NRE in response to human (including military) and natural stressors (Paerl et al., 2005). Specifically, there should be a strong emphasis on distinguishing regional from local, military, and non-military stressors and the impacts of these stressors on ecological condition and change in the receiving estuarine ecosystem. Research questions designed to address existing knowledge gaps and provide answers to management questions for the Aquatic/Estuarine Module include the following:

1. What nutrients are controlling the seasonal and annual productivity, biotic integrity, and natural resource values of the NRE?
   a. How are the nutrient inputs partitioned among atmospheric, surface, and subsurface sources?
   b. What are the relative proportions and roles of internally supplied versus externally supplied, point versus non-point source, and local (MCBCL) versus regional loadings of nitrogen and phosphorus to the NRE?
   c. How do these nutrient sources, loadings, and fates vary in the context of natural climatic variability and extremes? How does watershed condition exacerbate the impact of extreme climatic events?
   d. What is the trophic status of the NRE, and how is it affected by nutrient inputs?
2. Are there critical thresholds of nutrient inputs that fuel excessive primary production and disrupt food webs, thereby leading to eutrophication? Once these thresholds have been established, are key nutrient inputs controllable in the context of a practical, long-term nutrient management strategy for the NRE that meets MCBCL, state, and federal water quality criteria and accounts for climatic variability and extremes?
3. How does sediment loading affect productivity, nutrient cycling, biotic integrity, and habitat quality in the NRE? What is an acceptable level of sediment loading that promotes marsh accretion without impairing the function of the NRE?
4. Can we simultaneously examine and model the interactive effects of sediment, nutrient, and other pollutant input thresholds on productivity, biotic integrity, and resources?
5. What are the key sources (e.g., malfunctioning septic systems, runoff from land-applied sewage, spills or leaching from CAFO lagoons, discharges from WWTPs, discharges from onboard

toilets, or congregations of waterfowl) and indicators of fecal contamination in the NRE, and can the sources be controlled by an ecosystem-based management strategy?

6. How do physical forcings, including freshwater input, mixing/turbulence, light, and temperature fluctuations interact with the above stressors to modulate biological and chemical processes in the NRE?

7.2 Coastal Wetlands Module

Introduction

The coastal wetlands of the Coastal Wetlands Module are defined as the vegetated and non-vegetated intertidal habitats in salt and brackish waters, including adjacent tidal creeks for the purposes of characterizing utilization of marshes as nursery habitat by fishery organisms. The coastal wetlands targeted for this study include the salt marshes along the lower NRE shoreline and ICW to the brackish and freshwater marshes along the upper NRE shoreline and tributaries of the NRE. These areas within the MCBCL region are typically dominated by smooth cordgrass *(Spartina alterniflora*) and black needle rush (*Juncus roemerianus)*. The Coastal Wetlands Module's monitoring and research activities address challenges that are associated with stresses imposed as a consequence of MCBCL and other direct anthropogenic activities and of global climate change, particularly sea-level rise. Ultimately, these plans will provide MCBCL information needed to manage their coastal wetlands.

Key Physical, Chemical, and Biological Processes

Coastal wetlands are a vital component of the estuarine landscape that link terrestrial and freshwater habitats with the sea (Levin et al., 2001). Wetlands improve water quality by acting as nutrient transformers and trapping sediment; attenuate wind, wave, and boat wake energy; provide critical habitat area for a diverse group of estuarine organisms; serve as nursery habitat for commercially important fishery species; help to stabilize the coastal barriers; accrete sediments and build land; and provide recreational opportunities for people. The rate and magnitude at which these ecological processes occur is dependent upon a combination of biological characteristics of the marsh and physical and chemical characteristics of the environment. For example, the ability of marshes to trap sediment at a rate similar to sea-level rise depends upon sediment availability, the rate of sea-level rise, the density of marsh vegetation, storm intensity and frequency, and nutrient enrichment (Morris et al., 2002). **Figure 7-2** presents the conceptual model for the Coastal Wetlands Module, illustrating the complementary nature of these critical estuarine physical, chemical, and biotic processes and interactions.

Figure 7-2. Conceptual model for the Coastal Wetlands Module.

Coastal wetlands and adjacent uplands (including barrier islands) can be thought of as mutually dependent landscape elements. Wave energy impinging on salt marshes dominated by *Spartina alterniflora* is reduced by 50% within 10 meters of the marsh edge (Knutson, 1988), and sediment deposition rates are also highest at the marsh edge (Leonard et al., 2002). Single storm events may be responsible for the bulk of annual marsh sediment deposition, whereas marsh plant below-ground production (e.g., roots and rhizome biomass) can also result in increases in marsh elevation. In addition, marshes derive sediment from the overwash of barrier islands (Roman et al., 1997).

One of the ecosystem services provided by coastal wetlands is the support of the aquatic marine food chain, including commercially important species that use the marsh, such as blue crabs and shrimp (Currin et al., 1995; Dittel et al., 2000). The importance of marshes as nursery habitat is officially recognized by the North Carolina Division of Marine Fisheries through the designation of PNAs and secondary nursery areas, which result in the closure of tidal waters to activities such as trawling and dredging (See Appendix A for more information on PNA designation). There are many designated PNAs and secondary nursery areas within the NRE that limit use of these waters as military training areas.

Stressors

Threats to coastal wetlands include erosion from wind, boat wake, and intense coastal storms; dredging; trampling; subsidence due to compaction or fluid extraction; drought; and sea-level rise.

Military. Military activities at MCBCL have both direct and indirect impacts on coastal wetlands. Direct effects may result from amphibious Landing Craft Air Cushion (LCAC) operations through marshes, the launching of amphibious crafts at designate splash points along the estuarine shoreline, military boat traffic, military dredging and/or marina construction, and the potential of tracked vehicles operating over marshes. Indirect effects may result from runoff from training areas and impact zones. These activities may discharge dredged or fill material into wetlands or may degrade the condition of the wetlands by compacting marsh soils or destroying marsh vegetation.

Non-Military. Some of the same activities associated with military stressors also occur with non-military stressors, such as recreational boat traffic, commercial dredging and/or marina construction, and runoff

from commercial and residential development. Invasive and/or nuisance species are a growing issue for the management of coastal wetlands, particularly in areas subject to development and disturbance. In coastal wetlands on the Atlantic and Gulf coasts, an introduced strain of *Phragmites australis* has replaced millions of acres of marshland formerly occupied by *Spartina alterniflora* (Chambers et al., 1999; Saltonstall, 2002). Although millions of dollars have been spent in efforts to eradicate *Phragmites*, there is considerable debate over the justification for doing so because *Phragmites* marshes appear to be particularly effective in increasing the elevation of the marsh surface and offer many of the ecosystem services provided by *Spartina*-dominated marshes (Chambers et al., 1999; Meyer et al., 2000; Rooth and Stevenson, 2000; Leonard et al., 2002; Currin et al., 2003); however, *Phragmites* does not support the same consumer population as the native *Spartina*.

Legacy. Legacy effects to wetlands at MCBCL include the construction of the ICW, creation of dredge-spoil areas, ditching of salt marshes for mosquito control, and past dredging for management of the New River Inlet.

Natural. One of the main natural stressors to the wetlands is rising sea level as a result of climate change. The Intergovernmental Panel on Climate Change (IPCC) analysis of sea-level rise provides estimates ranging between 20 and 90 cm by the year 2100 (Houghton et al., 2001). The lower estimate is given by the least-sensitive model and assumes that carbon emissions are controlled. The upper estimate is from the most-sensitive model and assumes continued growth of carbon emissions. In all cases, a Greenland contribution of −0.02 to 0.09 meters is assumed. Recent data on the rate of melt of the Greenland ice sheet challenge this assumption. Polar warming by the year 2100 may reach levels similar to levels of 130,000 to 127,000 years ago that were associated with sea levels several meters above modern levels (Overpeck et al., 2006). The Greenland ice sheet and other circum-Arctic ice fields likely contributed 2.2 to 3.4 meters of sea-level rise during the last interglaciation (Otto-Bliesner et al., 2006). Even critics concede that the Greenland ice sheet contribution could be 1 to 2 meters (Oerlemans et al., 2006); thus, it seems likely that the estimates of sea-level rise will almost certainly be revised upward when the next IPCC report is issued in late 2007, and that conservative estimates could be on the order of 1 meter. Such a rise in sea level would result in significant relocations of infrastructure and habitats in the coastal zone. Much depends on how coastal wetlands respond to rising sea level and whether wetlands growth can keep pace with this rise. With or without sea-level rise, erosion occurs along estuarine shorelines as a result of wave energy. A recent estimate of shore erosion in northern North Carolina calculated an average rate of −3.2 feet/year, with maximum rates of −26.3 and −19.0 feet/year for high sediment banks and organic marshes on back-barrier islands, respectively (Riggs and Ames, 2003).

Linkages to Other Modules

Coastal wetlands and their attached barriers can be thought of as mutually dependent landscape elements. Barrier island overwash and flood-tide sediment deposition events can be instrumental in providing the sediment source for marsh building, and marshes provide the foundation upon which barrier islands can migrate. Barrier island fauna may also provide sources of nitrogen important to establishing new marshes and maintaining salt marsh primary production.

Salt marshes and estuarine water quality are linked by the twice-daily flooding of marshes by tidal waters. Estuarine waters are a source of sediments, salts, nitrate, and potential contaminants to salt marshes, which can influence marsh productivity and fish utilization. In turn, marshes contribute to water quality by transforming nitrate, largely through denitrification; sequestering and degrading contaminants; breaking down pathogens; and removing suspended sediments from the water column. Salt marshes reduce oxidized nitrogenous compounds to ammonium and particulate nitrogen and export these reduced forms to coastal waters (Valiela and Teal, 1979). Inputs of nutrients and fresh water via atmospheric deposition are potentially important controls on marsh primary production (Morris, 1991).

Marshes also migrate across the terrestrial landscape in response to sea-level rise (Gardner et al., 1992). This landward migration occurs with or without an increase in the elevation of the marsh platform in response to relative sea-level rise. One consequence of the migration is that total wetland area and total production will change depending on local geomorphology, anthropogenic barriers (e.g., bulkheads) to migration, erosion on the seaward side, and rates of marsh sediment accretion. Thus, the geomorphology of the terrestrial landscape adjacent to the marsh is quite important to the long-term survival of the marsh in the face of rising sea level.

Marshes are also linked to the terrestrial landscape through the movement of groundwater. Groundwater exits the terrestrial system into the estuary, but not before much of it moves through the marsh, where biogeochemical processes modify, decompose, or sequester many of the chemical species present. Thus, marshes exert an important control on the transport of nutrients and contaminants from terrestrial systems into the estuary.

Knowledge Gaps in the Conceptual Model

Our ability to predict and mitigate estuarine shoreline erosion is complicated by the fact that the wave environment in estuarine waters is changing as a result of more and larger-sized boats and their wakes. This is particularly an issue in the NRE, which is traversed by the ICW and supports a variety of military vessels and landing craft, as well as commercial and recreational watercraft. Shoreline stabilization of the land-water interface on the high wave energy oceanfront has been studied extensively (USACE, 1977). Less studied is the lower-energy portion of the estuarine shoreline, which often includes a more complex geomorphology and has also suffered considerable land loss (National Research Council, 2006). Numerous attempts at the stabilization of estuarine shorelines have been attempted, including the use of bulkheads, revetments, and other structures. However, shoreline hardening may result in alteration of the wave climate seaward of, and adjacent to, the shoreline, causing loss of intertidal areas, reduced sediment supply to adjacent areas, and a deeper nearshore region. In addition to these unintended consequences, there may be changes in habitat quality; modifications in biogeochemical cycling; effects on the light regime in the adjacent waters; and modifications in shoreline morphology. Either individually or collectively, these alterations may have profound implications for ecosystem services provided by these shoreline habitats. Given the importance of the estuarine shoreline for military training activities, as well as its role in protecting building structures, it is crucial that a plan be developed to address estuarine shoreline erosion within the NRE.

Marshes trap sediment, but whether or not they can keep pace with sea-level rise depends on sediment availability, the rate of sea-level rise, the density of marsh vegetation, the intensity and frequency of storms, and variables such as nutrient enrichment that affect the density of marsh vegetation and, potentially, the species of vegetation because of differences in the drag forces their canopies exert on flowing water (Morris, 1991). The vulnerability of coastal wetlands to sea-level rise is a function of the local tidal amplitude and marsh surface elevation relative to local mean and high water. As the rate of sea-level rise increases, the equilibrium elevation of the marsh will decrease. As this elevation approaches the lower limit of a wetland’s range of tolerance, the marsh will convert to open water upon any further increase in the rate of sea-level rise. Regarding the importance of plant community composition, the invasive species *Phragmites australis* is now common in the MCBCL region, but its history and current rate of spread are uncertain.

Fishery species show preference to some marsh habitats over others, and marshes in proximity to other estuarine habitats are particularly productive (Irlandi and Crawford, 1997; Micheli and Peterson, 1999); thus, not all marsh habitat is equally valuable as fishery habitat for aquatic organisms. Marsh areas within the MCBCL jurisdiction that serve as PNAs need to be identified, and their value as fishery habitat needs to be quantified (Meyer et al., 2000). The criteria used to delineate PNAs are not well defined.

Identification of the impacts of both environmental factors and military activities on the utilization of PNAs by juvenile fish and shellfish is a necessary component to an integrated ecosystem management plan.

Key Management Objectives

Coastal wetlands are the vital link between terrestrial and freshwater/estuarine systems. Management objectives in this ecological transition zone involve both the sustainability of military training activities, the preservation of the wetlands physical structure for protecting shorelines, and the function of wetlands for chemical processing to improve water quality. Key Base management objectives for the coastal wetlands of MCBCL include shoreline stabilization, attainment of CWA goals, wetlands restoration, control of invasive species, and accurate delineation of PNAs to maximize the area available for military training activities.

One key management objective is to stabilize the shoreline of the NRE, especially in areas that may threaten military structures (e.g., facilities, housing, and storage areas) or training uses (such as splash points where materials and troops are transported across the estuary). This includes understanding the relative impacts of recreational, commercial, and military boat traffic on the erosion of NRE marsh shorelines and the relative importance of boat wakes and wind waves. The importance of wind waves on shorelines depends on fetch, prevailing wind direction and speed, and local geomorphology. There is also a management need to understand what areas of the Base are most vulnerable to erosional forces so that these areas can be protected and to review past stabilization efforts, determine their success or failure, and recommend methods and candidate areas for future stabilization.

Another key management objective is to maintain the NRE’s aerial extent of coastal wetlands, which is dependent on sediment accretion and productivity. Salt marsh productivity and processes that depend on productivity are sensitive to salinity and nutrients. Freshwater discharge of groundwater is one of the factors controlling the salinity of marshes. Groundwater withdrawals are increasing with population density, and the impact of these increases on coastal marshes needs to be evaluated. The identity of the limiting nutrient (typically nitrogen) and the degree of nutrient limitation need to be established because increasing primary production by fertilization is a potential management option for increasing sediment accretion. Marshes can be managed in a variety of ways to increase sedimentation, but the relative success or practicality of different management strategies in the MCBCL region must be established. Moreover, the limiting rates on sedimentation need to be established to afford a means of predicting what the limits are for sea-level rise, (i.e., what rate of sea-level rise can the marshes tolerate?). Management options include the potential for using thin-layer dredge-disposal techniques on the marsh surface as a means of both disposing of spoil material and building marshes. There may also be opportunities for creating new marshes and constructing bulkheads (e.g., living bulkheads) that are ecologically benign and that protect the shoreline from erosion.

Preservation of the coastal wetlands and the function and processes that modulate water quality will further another of MCBCL’s key management objectives for meeting the requirements of the CWA. How wetlands may be utilized for water treatment purposes may provide additional options to the Base. For example, coastal wetlands can be utilized to treat secondary waste effluent, stormwater runoff, or land applications of treated sludge, but the feasibility of these options in the MCBCL region must be determined.

Another Base objective includes management of invasive species, such as *Phragmites australis. Phragmites* is invading wetland areas formerly occupied by *Spartina alterniflora*, especially in disturbed areas. *Phragmites* offers many of the same ecosystem services as *Spartina*–dominated marshes and is effective in increasing the elevation of the marsh; however, it may not support the same community of consumers. More information is needed to assist MCBCL resource managers in selecting a course of

action to eradicate or allow *Phragmites* to persist, as well as to identify what circumstances and methods would be most effective if the Base chose to eradicate this species.

The fifth management objective of the military is to increase use of certain PNAs for compatible training activities. PNAs provide important habitat (e.g., low salinity and abundant food) for juvenile fish species. Currently, the location of PNAs across MCBCL has an impact on military training options and land-use activities that occur in adjacent estuarine areas. MCBCL PNAs have been delineated by state agencies, but their quality as nursery areas has not been verified, nor have the impacts of military activities on their quality been assessed. The classification of French Creek is of particular interest because this waterbody is classified as a freshwater PNA, whereas other waters within the NRE are classified as saltwater PNAs.

Research Questions

The following research questions were established to address knowledge gaps in the conceptual model for the Coastal Wetlands Module and to provide answers to key management questions: .

1. What is the relationship between nutrient supply, marsh primary production, and sediment accretion rates? How does this vary along the estuarine gradient (e.g., barrier island to brackish tidal creeks), and how do military activities influence marsh primary production and the accretion rates? How do invasive species (*Phragmites australis*) alter marsh primary production, sediment accretion rates, trophic relationships, and habitat structure? What actions could be taken in areas that are particularly vulnerable to sea-level rise to enhance sediment accretion rates?
2. Are the structure and function of coastal wetlands impacted by the timing of training activities? If there is significant impact, what are the long-term recovery capabilities of those impacted wetlands from training?
3. What is the erosion rate of estuarine shorelines; how do military, recreational, and commercial vessels affect wave energy along the MCBCL shoreline; and what are the consequences of wave energy and shoreline erosion to the suspended sediment load in the estuary? What types of shoreline-stabilization approaches are cost effective under different wave energy regimes? Are there opportunities to restore salt marsh vegetation that utilize dredge spoil and/or that provide other benefits, such as shoreline stabilization or treatment of stormwater runoff?
4. How do the designated PNAs in the MCBCL region differ in terms of fishery utilization? What impacts do military activities have on PNA function? What are the linkages between estuarine water quality, benthic fauna, and the habitat value of PNAs? Can limited dredging operations be conducted in PNAs with minimal effect on habitat value? How do invasive species affect the fishery utilization of PNAs?
5. What are the sources of nutrient supply to marsh plants? Where are the important sites of shallow groundwater exchange with marshes and estuarine waters? What is the role of tidal marshes in the overall nutrient budget of the NRE? How effective are marshes in attenuating anthropogenic or atmospheric nitrogen inputs?
6. Can extreme climatic events result in insufficient or excessive sediment or nutrient loadings to the NRE?
7. What is the role in terrestrial and intertidal landscape three-dimensional structure, not just elevation at a point, in net sediment accretion? From where is the sediment coming from that facilitates marsh accretion?

7.3 Coastal Barrier Module

Introduction

The coastal barrier ecosystem lies at the interface between the continental shelf in the ocean and the protected estuary, extending from the shoreface toe at −10 meter water depth to the estuarine shoreline. This ecosystem encompasses the shoreface, tidal inlet, backshore beach, aeolian dune, shrub zone, incipient maritime forest, and washover sand flat habitats. These habitats are defined by intrinsic ecological processes, but are linked together by sediment transport, nutrient exchange, and biological uses, each of which undergoes substantial change over multiple time scales. Sustaining the integrity of environmental and mission-related assets through an improved understanding of ecosystem response to natural and anthropogenic forcing is the main goal of coastal barrier monitoring and research activities. The Coastal Barrier Module will examine the coastal barrier from the northeastern end of North Topsail Beach to Browns Inlet, approximately 8 coastline miles.

Key Physical, Chemical, and Biological Processes

The entire ecology of coastal barriers is organized directly and indirectly by the physical dynamics of meteorologically driven ocean forcing and the resulting sediment transport (Godfrey and Godfrey, 1976; Wells and Peterson, 1986) (**Figure 7-3**). Physical processes operating in the nearshore, including wind, waves, and currents, vary in magnitude on time scales from hours (e.g., coastal storms) and months (e.g., seasonal weather patterns) to years and decades (e.g., climate change). Sea-level rise is the background stage on which the physical processes are operating. The rate of rise is currently 3.7 millimeters (mm)/year at the NOAA tide gauge in Beaufort, NC, located 65 kilometers northeast of the study area, but this rate is predicted to accelerate because of global warming. Variations in the underlying geology and bathymetry of coastal areas influence how shorelines will respond (i.e., accrete, erode, change in sediment type) to different physical forcings (Kraft, 1971; Belknap and Kraft, 1985; Pilkey and Davis, 1987; Riggs et al., 1995; Thieler et al., 1995; McNinch, 2004; Rodriguez et al., 2004).

The intertidal portion of the shoreface enjoys high production of characteristic invertebrates, such as coquina clams and mole crabs, because of the high flux of suspended diatoms from oscillating wave action on shore. The high densities of these invertebrates qualify the intertidal beach as a key habitat, one that supplies food for abundant and valuable surf fishes, crabs, and shorebirds, including the piping plover (Federally Threatened), red knot (Candidate Species for Listing), and many other state and federal bird species of concern, such as the painted bunting (*Passerina ciris*) (Brown and McLachlan, 1990; Fraser et al., 2005; Karpanty et al., in press). Threatened species of sea turtles (loggerhead sea turtle and green sea turtle) lay eggs on the high beach during summer, which require about 60 days to develop and hatch. Predators influence the distribution, abundance, and breeding success of nesting sea turtles and nesting and migratory shorebirds and terns. Depredation of sea turtles and birds may alter rates of guano deposition on the barrier island and impact nutrient cycling.

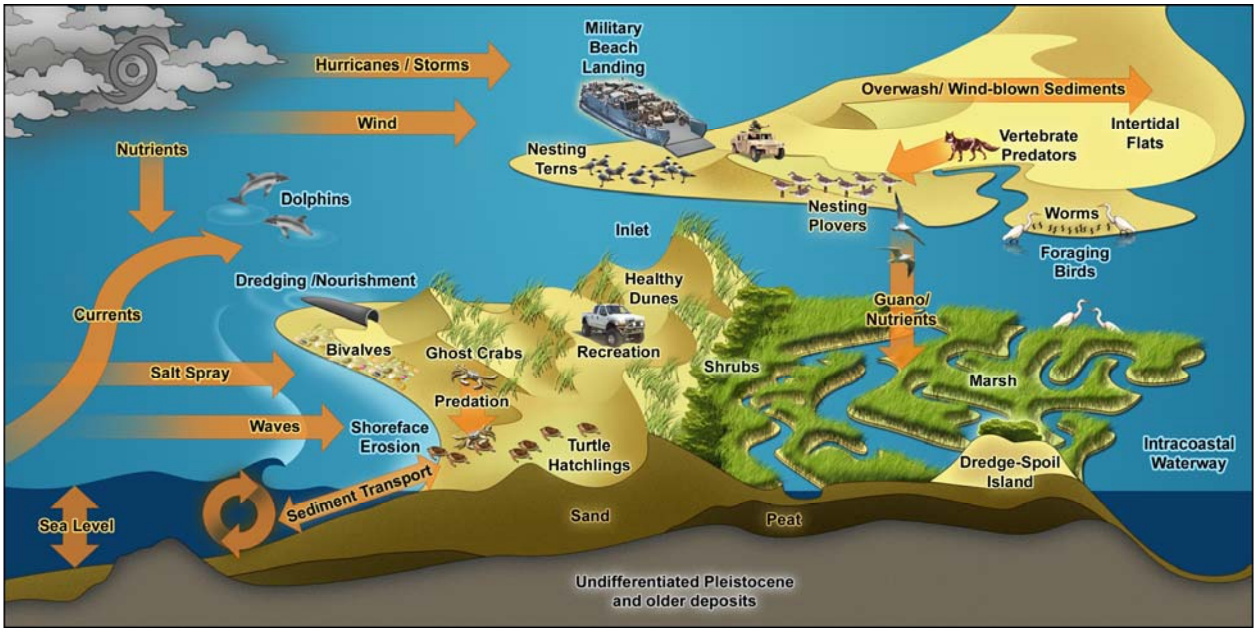


Figure 7-3. Conceptual model for the Coastal Barrier Module.

Low-lying coastal barriers, such as those of MCBCL, experience frequent overwash during storms. This process reinitiates the succession of dune and shrub-zone plant communities, provides new habitat for bird nesting and foraging, and extends and revitalizes salt marshes when overwash progresses across the island to the sound shoreline. Rare beach plants are sensitive to storm impacts, and some species, such as the seabeach amaranth, may even be enhanced by such perturbations. The dune and shrub plants of the coastal barrier suffer physiological stress from wind-borne salt spray, yet receive limited nutrients from that same source and atmospheric deposition (Au, 1974). The inlets of coastal barriers are especially dynamic, and storm overwash at inlets plays an important role in maintaining flat and sparsely vegetated areas suitable for nesting, roosting, loafing, and foraging by piping plovers, other shorebirds, terns, and gulls (Fraser et al., 2005).

Stressors

***Military*.** Part of the coastal barrier is important for amphibious military training, which occurs more than 250 days a year. During training exercises, the ecosystem receives significant boat, foot, vehicular, and low-level aircraft traffic. Training exercises impact the morphology of the barrier, both directly through sediment compaction and mobilization and indirectly through the degradation of dune plants that help trap and stabilize sand. Military traffic also may leave chemical residues (e.g., oil, gas) on the island. In addition, the north end of Onslow Beach is an impact area for exploded ordnance.

***Non-Military*.** The portion of the coastal barrier north of Risley Pier is reserved by MCBCL for recreation activities and receives vehicular traffic on the backshore and aeolian dune habitats. Other activities associated with recreational use, such as refuse disposal and housing construction (e.g., beach pavilion and cottages), may impact the conservation efforts for endangered species by attracting predators such as fox and raccoons. In addition, activities to build-up sand on the shoreline to protect housing and other structures from storms prohibits overwash and alters island structure. Other effects to the barrier island result from maintenance and commercial/recreational use of the ICW. Dredge material from the maintenance of the New River Inlet is periodically deposited onto Onslow Beach. Waterway dredging at inlets modifies currents and sediment-transport pathways, which may cause rapid morphologic changes to adjacent coastal barrier areas.

Legacy. Significant legacy effects to the barrier island exist because of the construction of the ICW. Periodic dredging of the ICW and New River Inlet is likely to have had a deleterious effect on those species that utilize sparsely vegetated flats adjacent to inlets (e.g., piping plovers and beach amaranth). In some places along the barrier island, the ICW was dredged only 250 meters from the ocean shoreline; thus, wakes and noise from commercial and recreational boats may impact shoreline structure and wildlife populations on the barrier island. The sand washed across the barrier island and into the ICW during large storms was dredged and deposited onto spoil islands to maintain navigability. Nourishment of the adjacent North Topsail Beach has altered sediment transport across the area.

Natural. Such natural phenomenon as seasonal storms and hurricanes temporarily stress the barrier ecosystem by causing rapid and extreme morphologic change. However, over the long term, storms likely yield a net long-term benefit to the ecosystem by redistributing sediment. The likelihood of shoreline erosion and washover is increasing due to an increased number of intense hurricanes and rising sea level caused by global warming (Barth and Titus, 1984). Although predation is a natural process in an ecosystem, unnaturally high levels of predation caused by the introduction of feral predators or the augmentation of the population of native predators can stress the biological components of this system. Dune structure and island stability may be altered by the introduction of invasive plants (e.g., *Vitex* sp.) or by drought conditions that affect plant communities.

Linkages to Other Modules

Ecological and morphological changes to the NRE’s coastal barrier directly impact the function of the adjacent ecosystems. The number and shape of inlets along a given stretch of barrier island changes through time, influencing estuarine salinity and circulation. Loss of dune vegetation reduces sediment trapping, causing dune elevation to decrease. This promotes washover during storm surges and the delivery of beach sand onto coastal wetlands. In contrast, nesting by ground-nesting shorebirds and seabirds is facilitated by reduced vegetation cover, so trade-offs exist among management goals for barrier-island ecosystems. During floods, sediment from the aquatic/estuarine ecosystem passes through the inlet, causing turbidity in the ocean and along the coastal barrier. Aquatic/estuarine ecosystem health impacts the availability of fish and invertebrates as food for coastal-barrier wildlife. Vertebrate predators and non-predators from the terrestrial ecosystem serve as a source population for the coastal barrier populations. Nutrients to the coastal barrier are modulated, in part, by atmospheric deposition and guano from birds feeding in the ocean, marsh, and estuary.

Knowledge Gaps in the Conceptual Model

The physical processes, morphology, and biology of barrier islands are interrelated, but the relative role of each in sustaining barrier function is unknown. Few studies of barrier islands are truly integrated; thus, they fail to support ecosystem-based understanding and management. An improved understanding of the morphological and ecological response of the coastal barrier ecosystem to changes in natural physical processes and anthropogenic stressors is critical for better shoreline management at MCBCL and elsewhere (Pilkey et al., 1993).

Variations in the underlying geology and principle sediment-transport pathways play a large role in modulating shoreline-erosion rates, but this has not been fully studied for MCBCL (Johnston, 1998; Cleary and Riggs, 1999a; 1999b; Filardi, 1999). Additionally, the biological responses to and sustainability for thresholds to physical, sedimentological, and morphological change are poorly understood (Peterson and Bishop, 2005). However, before we can fully understand these thresholds, it is necessary to fill in multiple knowledge gaps regarding the biotic community. For example, we do not know the factors that determine shorebird distribution, abundance, and reproductive success; sea turtle nest-site selection; or the distribution, abundance, and colonization of the coastal barrier by predators.

Key Management Objectives

There are two key management objectives for the Coastal Barrier Module. The first objective is the preservation of amphibious assault training areas of the coastal barrier on Onslow Beach. This coastal barrier is eroding most rapidly in areas where amphibious training exercises occur. Long-term erosion rates (1938–1992) vary significantly along short distances (Benton et al., 1993). For example, erosion rates decrease from >6 meters/year, adjacent to the New River Inlet, to <1 meter/year at the old Risley Pier, 5.8 kilometers to the northwest. To preserve the land mass in a form that sustains Base activities into the future, it is necessary to understand the causes of and respond to erosion-rate variability and to identify management options to enhance the physical structure of the beach.

In addition to the first management objective, a second objective is to preserve MCBCL barrier island habitat to sustain federally endangered and threatened species. Military training activities need to comply with the ESA as it applies to sea turtles, piping plovers, and seabeach amaranth. Management of the coastal barrier to enhance the productivity of listed species can be compatible with the sustainability of military activities. Such management may include protecting bird and turtle nests from predators or creating artificial washover areas or intertidal habitat for foraging. Development of ecosystem tools to manage the biological components of the coastal barrier, especially habitats for threatened and endangered birds, turtles, and plants, would require exploring new strategies to encourage federally protected and at-risk species to use non-military training areas of the barrier island for nesting and foraging. These strategies might also include determining the best frequency and methods for predator removal to benefit those species sensitive to predation, or determining what factors should be managed to improve the hatchling-survival rate of relocated turtle nests. The study of mitigation options will facilitate any habitat restoration that might be required if beach nourishment were proposed for the military training areas.

Research Questions

The following research questions will address knowledge gaps in the conceptual model for the Coastal Barrier Module and provide guidance on the management of military and environmental assets:

1. How are physical, sedimentological, and biological processes functionally interrelated to determine the state and dynamics of the barrier island ecosystem, thereby dictating shoreline erosion, island extent, and sea turtle and shorebird nesting? How do the impacts from Base activities compare to impacts from natural forcing processes in terms of intensity, and are these impacts synergistic or antagonistic? Can physical and botanical dune restoration and other management actions where natural and vehicular injuries have occurred restore environmental assets of value and buffer the island against subsequent shoreline erosion and island loss? How do nutrients cycle through the barrier island ecosystem, and how important are biotic components to that cycling?
2. Are long-term (e.g., decadal to millennial) patterns of shoreline erosion, island migration, and morphology inferred from photographic time series and stratigraphic analyses, derived in part from previous work (Johnston, 1998; Cleary and Riggs, 1999a, 1999b; Filardi, 1999), consistent with predictions arising from our short-term modeling of how bathymetry, subsurface geology, wave stress, and sea-level rise predict geomorphologic change? What inferences might be made from an empirical assessment of bathymetry surrounding Onslow Beach about the future site-specific risk of shoreline erosion and overwash? Where would beach replenishment, if needed, be most effective for enhancing military use and endangered species conservation? How does dredging the New River Inlet waterway affect Onslow Beach and endangered species conservation?

3. What are the trophic relationships and their variability between coastal barrier biota? How can management of native (e.g., ghost crab), introduced (e.g., red fox), and augmented (e.g., raccoon) predators improve the survival of hatchling sea turtles, shorebirds, and other species of concern?
4. Do benefits in augmented productivity of piping plovers, red knots, and other breeding and migratory shorebirds that may arise from vegetation clearing on historic overwash flats outweigh the disadvantages of losing the dune building that accompanies vegetational trapping of aeolian-transported sediments? What criteria should be used to establish an ecologically appropriate and sustainable balance?
5. How does critical foraging and nesting habitat for piping plovers and other shorebirds of concern depend upon the succession status and history of washover fans and their invertebrate prey community? How are washover areas formed and sustained, and are there techniques that can be applied to encourage their formation? Where should overwash areas be located on Onslow Beach?

7.4 Terrestrial Module

Introduction

The terrestrial ecosystem refers to the gradient of vegetation from salt marsh at the estuary margin, through brackish/freshwater marsh, to the longleaf pine savannas and pocosins (shrub bog) that dominate the terrestrial environments on MCBCL (Wells, 1942; Christensen, 2000). The gradients between these habitat types differentiate the terrestrial ecosystem of the coastal zone from that of inland sites, such as Fort Benning, where dry longleaf pine savannas and bottomland hardwoods dominate. Most of the rare species characteristic of coastal terrestrial ecosystems, including species of concern on MCBCL, are found in the transitional zones along these gradients. The studies in this module will be carried out at a variety of MCBCL locales, including the Great Sandy Run Area (GSRA).

Key Physical, Chemical, and Biological Processes

Variation in the biota and ecosystem processes along these gradients is driven by variation in hydrology, soils, and fire behavior. **Figure 7-4** presents the conceptual model for the Terrestrial Module, illustrating the complementary nature of these critical physical, chemical, and biotic processes and interactions. Salt marsh ecosystems are inundated daily with saline waters, and freshwater/brackish marsh ecosystem soils are frequently saturated with waters of lower salinity. Pocosin vegetation occurs on poorly drained organic soils and experiences infrequent (>40 years), high-intensity fires. Longleaf pine savannas generally occur on shallow organic and mineral soils; the depth of the water table in these ecosystems varies from a few centimeters to more than a meter, depending on topography, creating a gradient between dry upland savannas and wet flatwoods. These variations have significant effects on plant composition and diversity (Walker and Peet, 1984). The locations of transitions from one ecosystem to another along this gradient are often influenced by disturbance (fire) history (Garren, 1943; Christensen, 1981). Specific conservation challenges associated with different parts of these gradients include recovering the endangered red-cockaded woodpecker (RCW) in longleaf pine savannas, promoting herb diversity (e.g., Venus flytrap, *Dionea muscipula*) in wet savanna-pocosin transitions, and combating invasive species in freshwater marshes. Fire is a natural part of this landscape, and natural fire regimes (frequency and intensity) change across this soil-hydrology-vegetation gradient, from frequent surface fires in longleaf pine savannas to relatively infrequent and intense crown fires in pocosins.

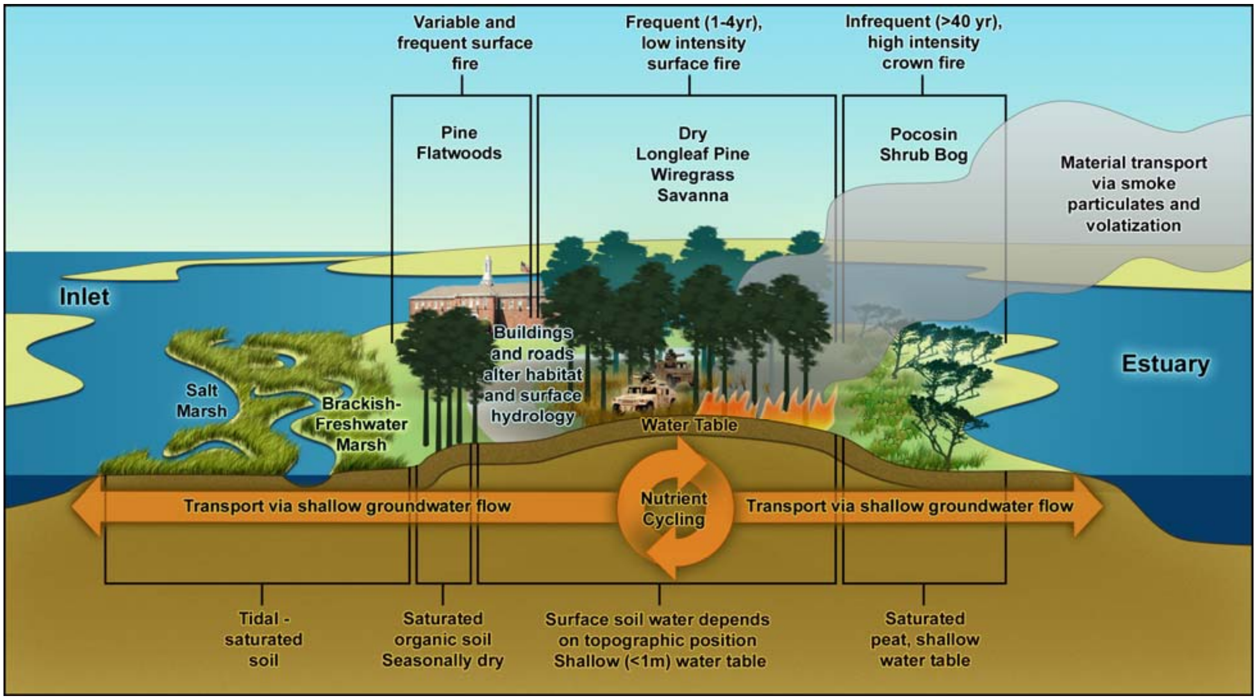


Figure 7-4. Conceptual model for the Terrestrial Module.

Fire and other forms of disturbance (e.g., soil compaction from vehicle traffic) interact with soil and hydrology gradients to determine the composition and condition of the plant community. Impacts at this level permeate through the food webs within the various habitat types to RCWs and other vertebrates on which habitat management is focused (James et al., 1997; James et al., 2001; Allen et al., 2006). Fire also mobilizes nutrient constituents of fuels to the atmosphere as particulates and gases, which fall to the forest floor as ash. These changes influence the total ecosystem capital of some minerals (e.g., nitrogen) and also influence their distribution and subsequent cycling (Christensen, 1977; Christensen and Wilbur, 1983; Christiansen, 1995).

The primary pathway for nutrient inputs to the terrestrial ecosystem follows wet and dry deposition from the atmosphere to the vegetation canopy. Across different stands within the terrestrial ecosystems, which may vary because of subtle differences in soil nutrients and soil drainage, the predominance of different tree cover may enhance deposition across a relatively wide area. Although net differences in deposition may be small on a yearly time scale between different tree stands, the accumulated difference across years can translate to variations in understory cover density and its capability to support the quantity and diversity of fauna and flora within the stand (Vogt et al., 1995), as well as to differences in overall stand vigor (Melillo et al., 1989). Because nutrients (especially nitrogen and phosphorus) limit productivity in these ecosystems (Christensen 1977, 1995), changes in nutrient allocation, inputs, and outputs are potentially important. The stand’s ability to quickly assimilate nutrients reduces loss to the underlying superficial aquifer and subsequent lateral transport to surrounding aquatic ecosystems; however, the efficient retention of nutrients within terrestrial ecosystems will also enhance potential nutrient remobilization and loss via atmospheric or aquatic pathways following natural coarse-scale disturbance events, such as wildfires or hurricanes. To a certain extent, prescribed burns will have to be considered wildfires until their effects toward sustaining the “natural” trend are better understood. The time scale for these nutrient losses is variable, with fires causing potentially large but short-term losses for and impacts to the aquatic ecosystems, and decaying vegetation and the sunlight penetration to forest floor of severely wind-damaged stands causing slower but consistently elevated nutrient losses.

Within a given tree stand, atmospheric deposition interacts with the micro-ecosystem that may develop underneath the canopy of an individual tree or nearby trees. Canopy drip under a single tree is not uniform and can result in micro-environments that are reinforced by the subtle differences in soil properties common in many areas of MCBCL. Such micro-environments can support plant diversity and development of soil fauna that may in turn be important to sustaining populations of larger predators, including migratory and resident birds on MCBCL. Therefore, changes in the composition and intensity of atmospheric deposition may aggravate changes in plant and fauna diversity at a greater frequency than would normally be expected in the typical life cycle of a given tree species. The repercussions of such changes could be expressed via differences in individual plant or animal distributions to changes in whole stand dynamics of fire-adapted ecosystems.

Stressors

Military. Building activities, roads, and other military land uses have altered vegetation cover and patterns of surface water movement in many MCBCL locations. Even where vegetation cover is relatively unaltered, terrestrial ecosystems are an important venue for a variety of military training activities. Foot and vehicle activity can compact soils and influence water flow and chemistry, which may directly affect the growth and survival of some plants and influence habitat quality for important animal species, including RCWs. In certain areas, ordnance impacts have altered surface topography, killed trees, distributed debris (including unexploded ordnance), and, occasionally, added to fire ignitions. Some terrestrial habitat has been converted to other land uses in support of military missions, in particular urban development within the cantonment area and cleared ranges and impact areas that are maintained in an early successional state. These alterations have increased habitat fragmentation, which may influence the biotic community directly through impacts on the dispersal of plants and animals, and indirectly by altering the spatial extent of fires and other physical processes.

Non-Military. Fire regimes have been altered over much of this landscape. In some terrestrial areas (e.g., flatwoods and pocosins), fire protection and suppression may have lengthened fire return times, thereby altering fuel conditions. Prescribed fire in some areas (longleaf pine savannas) may differ from historical fire regimes. Atmospheric deposition (wet and dry) of chemicals, most notably nitrogen, has increased over the past five decades due to off-site human activities. Land use changes from what was formerly forest has been converted to urban agriculture. Forest stands may be logged (i.e., clear cut or selective harvest) for revenue and/or as part of restoration activities. Buildings and roads create abundant impervious surfaces that influence the movement of surface waters and the penetration to shallow aquifers. Furthermore, various activities, including vehicle traffic, add materials to those surfaces that may alter the chemistry of surface waters in many places. Groundwater pumping may have altered aquifer levels and encouraged saltwater intrusion in places.

Legacy. The terrestrial landscape bears the legacies of hundreds of years of past human activities. Land clearing, agriculture, and land abandonment have altered many sites and continue to influence vegetation composition and structure. Historical logging and forest management have converted former uneven-aged longleaf pine stands to even-aged stands of loblolly and slash pines. Canals and drainage activities have altered local hydrology at some sites. Non-native species, some of which may be invasive, are now an important influence across the terrestrial landscape.

Natural. Periodic hurricanes and coastal storms influence forest structure and function. Sea-level rise, expected to occur in this region, may alter hydrologic and salinity gradients. These factors change naturally and may also be exacerbated by anthropogenic climate change. The results may be an increased risk of stand-replacing disturbance events.

Linkages to Other Modules

The topography of MCBCL differs greatly across the Base. Owing to relatively subdued topography and comparatively porous soils, surface runoff (and therefore, transport of materials in surface waters) is not an important linkage to other ecosystem modules in low-lying areas of the Base. However, in areas with an elevation of 75 feet above sea level, surface runoff is important, especially areas influenced by impervious surfaces, such as buildings, roads, and parking lots . However, mineral transport in shallow groundwater lenses may move nutrients from terrestrial ecosystems to tidal streams, wetlands, and the estuary. Large quantities of material are volatilized or lofted as particulates to the atmosphere during natural and prescribed fires. These dynamics are influenced by moisture, weather conditions, fire intensity, and the chemical characteristics of the fuel. Terrestrial ecosystems are habitat for such predators as raccoon, fox, and crow, which may also influence coastal barrier ecosystems. The numbers of these native and introduced predators are enhanced by human activities.

Knowledge Gaps in the Conceptual Model

There are several gaps in our knowledge related to the Terrestrial Module. Although the general relationship between fire and vegetation change is understood in longleaf pine forests, little is known about variations in natural fire regimes (e.g., frequency, season, and intensity of fire) along fuel and moisture gradients. This is particularly the case for pocosin and flatwood vegetation, and ecotones. The influence of such variations on total nutrient capital and patterns of nutrient cycling are unknown. Equally unknown is the influence of these variations on flowering and seed production of target plant species along the moisture gradient. The finer details of ecosystem variability and the characteristics and endemic species associated with unique habitats, such as lime sinks, are poorly understood.

The needs of RCWs are well known, but virtually nothing is known of community dynamics between the plants at the base of the food chain and the RCW at the top, or within the consumer community at the top beyond the RCW (U.S. FWS, 2003). New regulations from the U.S. Fish and Wildlife Service (FWS) have created a need for quantification of the quality of RCW foraging habitat. Little is known about RCW use of pond and loblolly pines within pocosin habitat. Most importantly, greater understanding is needed of how intensive management for RCW may affect other species.

The specific impacts of variation in human activities (e.g., foot and off-road vehicle traffic) on the interactions above are not well understood. Little is known regarding the effects of episodic disturbances such as hurricanes on plants and animals along the moisture gradient described above.

There is a lack of study of factors influencing the distribution of species of concern, including federally protected species, species at risk, and invasive species on this landscape. Such study may be particularly important for areas where land cover has been altered by building activity or along roads.

The impacts of forest management activities (e.g., logging and restoration) on plants and animals other than the target species (e.g., RCWs and pines) are not well known. Bio-solids are applied at localized sites, and their effects on vegetation composition and productivity have not been studied.

Pocosins are by far the least-studied terrestrial community in the Southeast. There has been limited study of their response to fire, and the dynamics of pocosin transitions to other ecosystems are of particular interest in this regard. Because considerable quantities of fuel are consumed in pocosin fires, the atmospheric emissions may be quite significant compared to fire in other ecosystems. The hydrology has been altered by canals in many pocosin sites, and little is known about whether and how to restore these areas.

Key Management Objectives

The terrestrial ecosystem portions of MCBCL, particularly the longleaf pine savannas, are focal locations for many activities central to the Base's mission, and these activities have important impacts on the ecosystems along this gradient. Because of this, MCBCL devotes much of its management resources to terrestrial ecosystems, most especially through its timber management and fire management programs. A better understanding of the functioning of the entire terrestrial ecosystem will enable managers at MCBCL and at other facilities in coastal environments to better integrate training with natural resources management objectives, such as forest sustainability, habitat restoration, and endangered species management.

Fire management to maintain the habitat of federally protected species and other species at risk ranks high among management objectives. In the case of prescribed fire, the goal is to find optimal frequencies and burning seasons for the maintenance of species diversity, the improvement of RCW habitat, and the minimization of wildfire risk. In areas with heavy fuels such as pocosins, managers are interested in strategies to minimize wildfire risk, including prescribed fire. Other management strategies are also of interest, such as mowing and transplanting to increase the viability of rare species and minimize the impact of invasive species.

The management of RCW populations remains a very high management priority. Objectives include increasing the number of RCW clusters, finding mechanisms to recover bird populations while restoring longleaf pine, and the possible utilization of pond pine as RCW habitat. Managers need cost-effective metrics of habitat quality for RCWs and other threatened species. Possible credit for the establishment of RCW clusters off the Base is of particular interest. Minimizing the effects of military maneuvers and training on RCW populations and other sensitive species is another key management objective. The management of RCW populations should align with other conservation objectives, including maintaining populations of other bird species.

Given the legacy of past activities, restoration of longleaf savanna and flatwood communities is a priority management objective in many areas. This includes the development of strategies for the reintroduction and propagation of wiregrass and forestry activities, such as thinning and planting to accelerate the recovery of longleaf pine and the conversion of off-site loblolly pine to longleaf pine.

Drainage structures in parts of the GSRA have altered vegetation and increase the likelihood of wildfire in some pocosin areas; therefore, managers are interested in options for restoring hydrology in such areas. In other areas, vegetation change (e.g., increased undergrowth) is creating conditions unsuitable for military training activities.

Research Questions

The RTI DCERP Team's strategy will address a number of specific management issues, including the effectiveness of PB, management of foraging habitat for RCWs, characterization of habitat requirements of other species at risk, and impacts of tactical vehicles on ground cover vegetation. The following research questions address knowledge gaps in the conceptual model for the Terrestrial Module:

1. What are the effects of variations in fire regimes (e.g., fire frequency, severity, and season) along soil moisture gradients on vegetation composition and structure, faunal communities, and fuels?
2. How best do we define, measure, and monitor good quality habitat for RCWs and determine the impact of improving habitat quality for RCWs on other components of terrestrial communities?
3. What are the impacts of off-road vehicle activity on soils, flora, and fauna in the context of fire and hydrologic gradients?

4. What landscape and environmental features are most important in predicting the distribution of at-risk species or invasive species? What are the impacts of invasive species, and can ecosystem resistance and resiliency to these species be enhanced?
5. What natural resource values and management options (including fire) exist for pond pine pocosin? Can these options impact the use of pocosins by federally protected species and other species at-risk?
6. How do prescribed fire and other management activities affect overall nutrient cycles and the transfer of nutrients to the atmosphere or, via groundwater, to other nearby ecosystems?
7. How do anthropogenic influences on nutrient cycles affect ecosystem diversity and function?
8. What are indicators of terrestrial ecosystem health that can be easily monitored?

7.5 Atmospheric Module

Introduction

The atmosphere represents one of the major pathways for the transport of nutrients and pollutants into and from terrestrial and aquatic ecosystems (Lawrence et al., 2000; Paerl et al., 2002). It is also one of the primary pathways for the redistribution of nutrients and pollutants observed along coastal areas (Melillo et al., 1989). Because transformations of various gaseous and particulate species occur in the atmosphere, while being transported, a broad scope of emissions needs to be quantified. These transformations occur in the presence of other atmospheric constituents that are derived from local and regional sources, further complicating attempts to attribute or predict impacts from emissions associated with MCBCL activities on neighboring communities. The vegetative cover of the terrestrial ecosystem at MCBCL represents a large surface area that promotes atmospheric deposition. Atmospheric deposition, in turn, represents an input into both the terrestrial and aquatic ecosystems. Nutrients and pollutants from atmospheric deposition are incorporated into nutrient cycles within the respective ecosystems at the Base, exerting their influence on various time scales, depending on the nature of the ecosystem itself and activities undertaken by MCBCL staff to optimize their primary training mission. The proximity of MCBCL to the near-coastal environment adds another level of complexity because the presence of marine-derived sea salt aerosols (SSA) imposes a natural gradient of deposition across the Base and also exerts an influence on atmospheric transformations not typically encountered farther inland (Andreae et al., 1986; O'Dowd et al., 1997).

Key Physical, Chemical, and Biological Processes

Atmospheric Deposition. The input of nutrients and pollutants via atmospheric deposition interacts with most key terrestrial and aquatic ecological processes occurring at MCBCL, as illustrated in **Figure 7-5** and as reported for similar ecosystems (Van Der Salem et al., 1999; Lawrence et al., 2000). Atmospheric deposition is the only direct input to the surface of open waters of the aquatic ecosystem, but the frequency and composition of this input is as important in influencing flora diversity. Changes in the dominant forms of a given nutrient (e.g., nitrogen) over time will lead to shifts in the dominant flora within the aquatic ecosystem (Paerl et al., 2002). Such changes will impact the entire food chain of the ecosystem, as well as the system's ability to respond to natural disturbances induced by storm events and tides. The aquatic ecosystem also is impacted by atmospheric deposition after it is filtered and altered by passage through the terrestrial ecosystem. Sensitivities of nutrient inputs to the terrestrial ecosystem have been described earlier as key processes in the Terrestrial Module (Section 7.4). This impact occurs on all time scales, from rapid inputs following large rainfall events (runoff) to slow but critical changes in baseflow from the superficial aquifer (Hunsaker et al., 1994; Osgood and Zaeman, 1998). It may not always be immediately evident which impact is playing the dominant role in forcing change within the aquatic ecosystem.

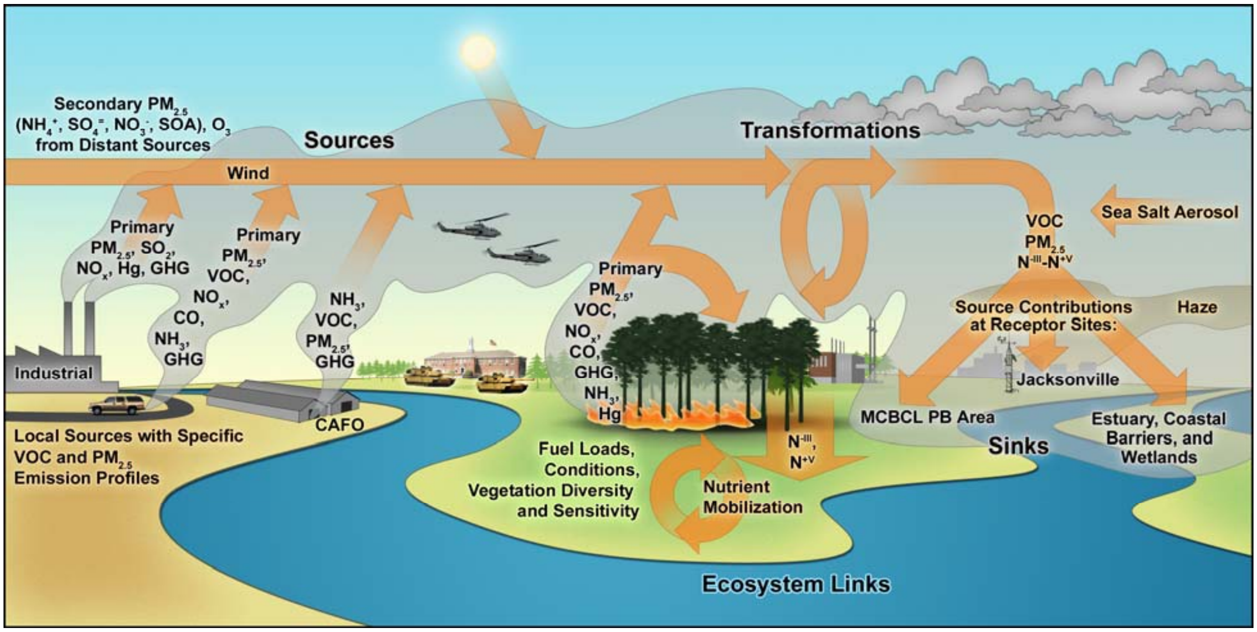


Figure 7-5. Conceptual model for the Atmospheric Module.

Dry deposition of atmospheric constituents, either nutrients or pollutants, is directly dependent on their ambient concentration near the ground. These concentrations are influenced by different anthropogenic and biogenic sources; meteorological conditions driving their atmospheric dispersion and transformation; and sinks (see **Figure 7-5**). Ammonia can dry deposit as a gas. Ammonia, along with nitrogen oxides, sulfur oxides, and chlorides, is also a precursor to secondary $PM_{2.5}$ formation. Increased nitrogen oxides and ammonia emissions and the formation of fine particulate matter ($PM_{2.5}$) alter patterns in atmospheric deposition through changes in the amount, composition, and distance of transport. Volatile organic compounds (VOCs, also regulated under the Clean Air Act [CAA]) and nitrogen oxides are precursors to ozone formation. Among the six criteria air pollutants regulated for the protection of human health under 40 Code of Federal Regulations (CFR) of the CAA, ozone, and $PM_{2.5}$ are the most difficult to control because they are products of complex atmospheric formation processes involving heterogeneous photochemical reactions of certain precursors (U.S. EPA, 1996; U.S. EPA, 1997; Seinfeld and Pandis, 1998). Additional information on the CAA and the regulations implemented by the North Carolina Division of Air Quality (NCDAQ) is available in Appendix A.

Prescribed Burning. Fire is a natural part of the landscape, and natural fire regimes (e.g., frequency, intensity, and season) vary across this soil-hydrology-vegetation gradient, from frequent surface fires in longleaf pine savannas to relatively infrequent and intense crown fires in pocosins (Kodama et al., 1980). Prescribed burning (PB) was used by native Americans for improving access, hunting, and farming and was adopted by the early European settlers. By the 1980s, PB had become the dominant land management tool in the southeastern United States, and MCBCL managers have implemented this technique to reduce wildfire risk, manage range and forest ecosystems, and provide and maintain terrain for training and testing. PB activities are also mandated by the ESA to recreate the natural fire regimes needed to maintain the health of native forest ecosystems and, thus, to protect the habitat of threatened and endangered species. Despite its essential ecosystem benefits, PB is a major source for $PM_{2.5}$ and other air pollutants due to its incomplete and largely uncontrolled combustion process, which involves flaming and smoldering phases with different effective fuel consumption, unknown ecological sensitivities toward burning conducted in growing versus dormant seasons (Johnson et al., 1998), and unclear ecological benefits on larger spatial and temporal scales (Maclean et al., 1983; Raison et al., 1985). Certain fuel and fire meteorological parameters influence the emissions from the different combustion phases, which in

turn participate in transport processes within the atmospheric boundary layer, causing air quality impacts on local to regional scales (Lee et al., 2005; Friedli et al., 2007).

Stressors

The air quality over MCBCL has the potential to stress Base ecosystems via the physical, chemical, and biological processes previously described, such as atmospheric deposition; runoff of nutrients deposited on terrestrial systems; and flora, fauna, and structural exposure to airborne pollutants. It is important to understand emission sources that contribute to air quality and subsequently impact ecosystems. The following discussion addresses the first of the two-step process of ecosystem stress, i.e., the stressors to air quality, with the understanding that by developing strategies that control, alter, or mitigate stressors to air quality, MCBCL ecosystems will in turn be less stressed.

Military. The impacts of MCBCL on atmospheric processes are both direct and indirect. Military activities on the Base can change and potentially alter emissions of various gases, including the regulated criteria pollutants (e.g., sulfur dioxide, nitrogen oxides, carbon dioxide, and VOCs) and ammonia. Emissions of fine and coarse primary PM (regulated as $PM_{2.5}$ and PM_{10}) may change. These emissions are associated with military vehicles (e.g., aircraft and land-based); stationary sources; sewage handling and disposal activities; and general maintenance activities (e.g., painting) to keep the Base functional. These emissions directly impact local atmospheric deposition and interact in the atmosphere with transported constituents from other local and distant sources to form secondary pollutants, principally ozone and additional $PM_{2.5}$. The presence of ozone is an immediate stressor that can directly impact ecosystem flora and fauna health and human health. It can also degrade exteriors of MCBCL structures.

Non-Military. The presence of MCBCL results in increased activity within the Jacksonville, NC, urban area, both in civilian traffic to and from the Base and the other associated activities necessary to develop the surrounding community for the support of the Base. Growth in the Jacksonville area, as with much of the North Carolina coastal area, will result in increased regional air emissions. MCBCL is positioned downwind from Jacksonville, NC, which borders to the north, as well as New Bern, NC (25 miles northeast); Wilmington, NC (30 miles southwest); and Raleigh, NC (90 miles northwest).

Non-military-induced stress has also arisen from the necessity to use PB to manage the large acreages needed to meet the training goals of MCBCL. In addition to the release of gases and VOCs, PB releases smoke, which adds to regional haze and alters (at least for a certain period) the ability of an ecosystem to respond to atmospheric inputs or lessen transport into the aquatic ecosystem, either by runoff or through the superficial aquifer. PB activities may also enhance the redistribution of nutrients within relatively short distances because the intensity of the burn is insufficient to lift the larger particulates and ash above the canopy (Raison et al., 1985). Terrestrial ecosystems immediately downwind of a burn may experience an enhanced input of nutrients as ash and particulates accumulate in the canopy and are then removed by subsequent rainfall events. The Holly Shelter-Angola Bay area in neighboring Pender County, NC, to the west of Onslow County is part of the state-owned Game Lands system managed by the North Carolina Wildlife Resources Commission; therefore, like MCBCL, this area is subject to frequent prescribed burns, causing emissions that may impact MCBCL. In addition, the Sutton coal-fired power plant in Wilmington, NC (30 miles to the southwest), may cause episodes of elevated air pollutants.

All of these factors have resulted in an increase in atmospheric deposition of nutrients and pollutants within the region over the past few decades, with changes not only in total deposited amounts but also in composition of the more dominant species (especially nitrogen). Due to its location in the eastern United States, MCBCL has experienced elevated amounts of various nutrients in wet deposition during the past 30 years. The nature and amount of the wet deposition is well documented by the presence of three National Atmospheric Deposition Program (NADP) collectors positioned across the Coastal Plain region of North Carolina. For the past ~10 years, the amount of ammonia wet deposition in the Coastal Plain

region has essentially doubled due to ammonia emissions from CAFOs, and it is logical to assume the amount of dry deposition of nitrogen has also increased. MCBCL is located directly east of an area with the highest density of CAFOs in the North Carolina Coastal Plain (Walker et al., 2006).

Two collectors from the Mercury Deposition Network of the NADP are also located in North Carolina. Both collectors are located along the coast, with the Base located approximately midway between them. Operational since 1998, these collectors confirm that mercury deposition along the coast of North Carolina has remained constant for almost 10 years and similar in magnitude along much of the eastern coastline for the United States, from North Carolina southward (http://nadp.sws.uiuc.edu/mdn/). It should be noted that mercury is a bioaccumulative neurotoxin to humans. Whether deposited from the atmosphere and converted to methylmercury in aquatic systems or discharged in waters, mercury in eastern North Carolina fresh waters and salt waters has become a concern. Fish consumption advisories have been issued for certain freshwater and saltwater fish high on the aquatic food chain.

Legacy. No legacy stressors were identified by the Atmospheric Module Team.

Natural. Atmospheric events that stress the MCBCL ecosystem and are based on natural processes cannot easily be distinguished from anthropogenically induced stressors and, therefore, require a definition. The RTI DCERP Team considers processes of certain temporal and spatial scales to be natural stressors, including global climate changes that have local impacts from directly associated short-term events (e.g., hurricanes) and smoke from large wild fires in remote boreal regions. Both events may cause a short-term increase in regional ozone because of deep convective mixing, allowing for the intrusion of stratospheric ozone and photochemical production of ozone under favorable conditions in a wildfire plume, respectively (Wotawa and Trainer, 2000). However, we realize that global climate change is induced by emissions of radiatively active gases and particulate matter, land-use modifications, and other human activities, and has the potential to feedback and affect regional air quality over the long term. Such changes may be manifested over a variety of urban, regional, and global scales. For example, a change in ground cover due to human activities or in response to climate change will impact local heat transfer (as evidenced by urban heat islands) and the emissions of shorter-lived, photo-chemically active gases, including VOCs and nitrogen oxides. Global climate change will also impact energy demand, affecting nitrogen oxides, sulfur dioxide, mercury, and particulate matter emissions, which in turn impact regional pollutant concentrations. The RTI DCERP Team will consider these emissions as regional background levels subject to long-term trends.

Linkages to Other Modules

Except for nitrogen-fixation by native plant species, inputs from migrating wildlife, and nutrient releases from soil weathering, atmospheric deposition represents the only source of new nutrients into the terrestrial ecosystems at MCBCL. Knowledge of the amount, composition, and frequency of inputs are necessary to assess the sustainability of current terrestrial ecosystems and to determine long-term sustainability in regards to native flora and fauna, as well as to the training mission of MCBCL. Wet deposition can be estimated from rainfall records, whereas dry deposition (which will be at least equal to wet deposition) must be estimated from on-site measurements. Changes in forest management (such as thinning and clear cutting) will have direct impacts on atmospheric deposition and nutrient inputs. The short-term capabilities of forests to retain nutrients from atmospheric deposition will be influenced by the frequency and acreage of prescribed burns (~ 25,000 acres per year), which illustrates the linkage between the Atmospheric Module and the Terrestrial and Aquatic/Estuarine modules. Since PB is primarily confined to the first 5–6 months of the year, there may be a strong temporal interaction between these three modules.

PB is an essential tool for maintaining ecological health in natural fire regimes; however, increasing pressure from air quality regulators calls for minimizing impacts from smoke emissions. Most military

installations in the United States use PB to maintain property for training. Guided by the ESA, the U.S. Department of Interior (DOI) mandates that most military installations in the Southeast use PB to maintain native forest ecosystems and protect threatened and endangered species habitats. MCBCL's annual PB target is 25,000 acres burned between December and May. The current fuel model aids in the PB planning process by prioritizing certain ecological criteria, including longleaf plantations, threatened and endangered plant species, RCW recruitment sites and clusters, and time since last burn, among others. Data availability, redundancy, value in maintaining ecosystem integrity, and desired future landscape conditions are additional criteria considered in the decision-making process. Once MCBCL identifies the areas that have been scheduled for PB, a dispersion model interface is used in conjunction with a nationwide database. This database includes information on surface wind and a ventilation index that is the product of wind speed and mixing height. MCBCL land managers currently derive the ventilation index from the National Weather Service's daily fire weather forecast from http://fire.boi.noaa.gov/ FIREWX/RDUFWFMHX.html, with which they determine the burning category via http://www.dfr.state.nc.us/fire_control/fire_category.htm and ultimately the target amount of PB acres from the smoke management tonnage table at http://www.dfr.state.nc.us/fire_control/smoke _guidelines.htm. This procedure is relatively weak in predicting how fast and in what way fuel will burn and currently does not contain a processor that considers fuel chemistry or fuel characteristics relative to what PB emits from vegetation and soil overall or, more specifically, during the different combustion stages (i.e., flaming and smoldering). Also, no distinction is currently being made between primary PM emissions and secondary PM formation from gaseous precursors, especially organic compounds whose atmospheric processes are largely unknown (Robinson et al., 2007).

The vegetation gradient at MCBCL is exceptionally steep, spanning from salt marshes at the estuary margin, through brackish/freshwater marshes, to the longleaf pine savannas and pocosins (shrub bog). Variation in the biota and, hence, fuel mix and load along this gradient is driven by variation in hydrology, soils, and fire behavior. These differences in vegetation composition, soil composition, and soil/fuel moisture will cause significant variations in the combustion process. Combustion can be divided into flaming and smoldering processes. Flaming combustion occurs at temperatures greater than 1500 °C for brief periods early in the burn when the most volatile compounds heterogeneously react in the gas phase. Flaming almost completely oxidizes the fuel to the most common gas and particle oxides. Smoldering combustion occurs for hours or days after flaming combustion subsides or in areas with high fuel moisture. Smoldering at the fuel surface produces significant quantities of particles largely by the condensation of volatilized organics from incomplete oxidation. As a result, the amount and composition of gas- and particle-phase species emitted as the combustion process evolves during a PB will depend on the fuel characteristics.

A large fraction of PB-generated smoke is primary organic aerosols directly emitted into the atmosphere. The organic portion is the least-understood component of $PM_{2.5}$, However, $PM_{2.5}$ is not only made up of such primary emissions; a secondary aerosol fraction resulting from the reaction of VOC in the atmosphere is an important contributor. This secondary organic aerosol (SOA) fraction is extremely complex because the precursor VOC can originate from many different sources besides PB and can constitute a significant portion of ambient $PM_{2.5}$ (Turpin and Huntzicker, 1995). The Fractional Aerosol Coefficients, developed and first published by Grosjean and Seinfeld (1989), is a very crude first-order approximation of potential SOA formation, which can be estimated for VOC emissions from the different fuel-linked test fires. Thus, relationships can be established between certain fuel/vegetation conditions, burning stage, season, and PB VOC emissions' potential for creating SOA downwind.

Atmospheric deposition can represent a significant percentage (20% to 50%) of new nutrients introduced into the different ecosystems investigated (Paerl et al., 2002). Knowledge of the composition of atmospheric inputs is particularly important to assess sustainability. The degree of atmospheric inputs to coastal barrier and coastal wetland ecosystems may be markedly enhanced by the presence of marine

aerosols (e.g., SSA). The presence of SSA can alter the partitioning between gases and particulates in the atmosphere, favoring the retention of gases (such as ammonia and nitric acid) on larger particles. Larger particles have higher deposition rates, thus effectively increasing the net dry deposition of a gaseous species. In turn, this may increase overall atmospheric deposition within the coastal barrier and coastal wetland ecosystems.

Airborne transport crosses watershed and state boundaries. Any impact observed on the habitats of interest must take into account sources of airborne pollutants transporting into and depositing on the area (via wet and dry deposition), as well as sources within MCBCL and subsequent transport of locally derived airborne pollutants. The NRE, MCBCL, and surrounding coastal waters lie directly east of Sampson and Duplin counties, which have the highest density of CAFOs in the United States (McCulloch et al., 1998). Ammonia emissions from these operations have impacted rainfall chemistry in the region (Walker et al., 2000b) and increased nitrogen deposition up to 80 km away (Walker et al., 2000a), which is within range of the NRE, MCBCL, and surrounding waters.

The vegetative cover of the terrestrial ecosystem at MCBCL represents a large surface area that promotes atmospheric deposition. Atmospheric deposition, in turn, represents an input into both the terrestrial and aquatic ecosystems. Nutrients and pollutants from atmospheric deposition are incorporated into internal nutrient cycles within the respective ecosystems at the Base, exerting their influence on various time scales, depending on the nature of the ecosystem itself and activities undertaken by MCBCL staff to optimize their primary training mission. The proximity of MCBCL to the near-coastal environment adds another level of complexity because the presence of marine-derived SSA imposes a natural gradient of deposition across the Base and also exerts an influence on atmospheric transformations not typically encountered further inland (Andreae et al., 1986; O’Dowd et al., 1997).

Ozone is linked to the Terrestrial Module in multiple ways. First, ozone can damage vegetation. Second, ozone formation can be influenced by biogenic emissions from vegetation (e.g., isoprene) and from PB emissions. Therefore, understanding the contribution of the ozone precursors (VOCs and nitrogen oxides) from local off-site sources can promote a better understanding of ozone formation in MCBCL. $PM_{2.5}$ is also documented as damaging to vegetation. It is linked to the Terrestrial Module because it can be generated by PB, as well as land-based and amphibious operations that combust fuels. (Diesel fuel and coal combustion emit $PM_{2.5}$, as well as NO_X, which is a $PM_{2.5}$ precursor.) Nitrogen deposition as ammonia, NO_X, or ammonium nitrate $PM_{2.5}$ is linked to the Aquatic/Estuarine Module because MCBCL is located in nutrient-sensitive waters susceptible to eutrophication from nitrogen loading increases.

Knowledge Gaps in the Conceptual Model

There are several gaps in our knowledge concerning the Atmospheric Module relating to deposition, emissions, PB, and influences from the ocean.

Deposition

There are several knowledge gaps associated with atmospheric deposition. The source apportionment of nutrients from atmospheric deposition (especially nitrogen) to estuarine waters derived from direct deposition, or indirectly via surface runoff or superficial groundwater, is unknown, as is the percentage of deposited nutrients that is incorporated into terrestrial ecosystems and the micro-environments within these ecosystems every year. The impacts that the current level of wet and dry mercury deposition are having on the flora and fauna and on potential long-term sustainability of the terrestrial and aquatic ecosystems within MCBCL are also unknown. Atmospheric ozone can act as a surrogate air quality indicator of ecosystem stress; however, the spatial and temporal patterns of ozone exposure across the various MCBCL terrestrial ecosystems are unknown. The presence of significant stress due to ozone exposure would compound impacts from atmospheric deposition. The predominantly sandy texture of the

majority of soils at MCBCL will promote rapid infiltration of rainwater and subsequent movement of atmospheric deposition to the underlying superficial groundwater. In addition, the relationship between significant rainfall events, evapo-transpiration demand of the terrestrial canopy, and the residence time within the superficial groundwater has not been established for the various surface waters at MCBCL.

Emissions

Limited understanding also exists of mobile/stationary emissions and emission profiles for MCBCL. An estimate of the emissions associated with military vehicles (e.g., aircraft and land-based), certain stationary sources, sewage handling and disposal activities, general maintenance activities (e.g., painting), and PB is not available for MCBCL. In addition, projections of continued and future atmospheric deposition across MCBCL's terrestrial and aquatic ecosystems requires an assessment of spatially resolved emission source terms that may be contributing to the overall inputs; however, this assessment is unavailable for MCBCL.

Prescribed Burning

Relatively low-intensity burns result in ash and particulate transport to nearby unburned terrestrial ecosystems. The qualitative and quantitative aspects (e.g., influence of fuel load, initial fuel conditions, vegetation diversity, composition of emitted ash, particles and gases) of this nutrient redistribution are unknown, especially when PB is restricted to only a few windows of opportunity, typically within a 6-month period (December to May) of the year, which results in intense activity and redistribution over a relatively short period of time. In addition, fuel combustion during PB is highly incomplete, mainly due to the underlying soil; thus, emissions have relatively little thermal buoyancy, allowing significant residence time of the plume within the canopy. The fraction of the emitted nutrients retained (including the fraction deposited to the canopy and subsequently returned to the soil via precipitation through fall/stem-flow) versus the fraction of pollutants released for regional dispersion is unknown. Prescribed burns can result in short-term (days to months) changes at the soil-vegetation interface and lead to conditions that may enhance emissions of gases, such as ammonia and nitrogen oxides. The amount and frequency of soil gaseous emissions following prescribed burns is unknown for MCBCL terrestrial ecosystems, as is the amount of mercury locked in MCBCL's forests and potentially released during PB. Mercury deposited to the ecosystem via wet and dry pathways is trapped and predominantly locked in the upper organic soil layers of northern latitude forests, making PB an important mechanism for mercury release and atmospheric redistribution (Friedli et al., 2007). Lastly, more comprehensive emissions data are needed on flaming versus smoldering of fire during prescribed burns, as well as on how prescribed burns differ from wildfire events.

Ocean Influence

Close proximity to the open ocean can markedly alter the air circulation and residence time of atmospheric air masses. This can result in errors in model projections of atmospheric composition and deposition based on meteorology from more inland locations. The understanding of the seasonality of air circulation patterns and meteorology for MCBCL remains incomplete. In addition, the proximity of MCBCL to the open ocean influences aerosol formation. The extent and influence of SSA on atmospheric processes are not well known, including the gradient in SSA deposition moving inland, enhanced dry deposition of gaseous nitrogen species due to partitioning onto relatively large SSA, and the potential for SOA formation (Spokes et al., 2000; Tanaka et al., 2003; Cai and Griffin, 2006).

Key Management Objectives

1. Sustainability of current terrestrial ecosystems. Most military installations in the United States use PB to maintain property for training. Guided by the ESA, the DOI mandates that most military installations in the Southeast use PB to maintain native forest ecosystems and protect threatened and

endangered species habitats. As a result, MCBCL prescribes burns 20,000–25,000 acres annually. One tool used in planning PB is a fuel model, which is designed to predict how fast and in what way fuel will burn. It currently does not contain a processor that considers fuel chemistry or fuel characteristics relative to what PB emits from vegetation and soil.

Through proposed research and monitoring, DCERP will be provided with input to terrestrial ecosystem sustainability by contributing data to help fill gaps, including

1. Effects of variations in fire regimes (e.g., frequency, season and intensity of fire) along fuel and moisture gradients.
2. Connections between fire regimes, herbaceous communities, and habitat for insect and bird communities
3. Improved understanding of these PB effects at the moist, e.g., pocosin, end of the moisture gradient.

The long-term sustainability of terrestrial ecosystems is critical to the training mission of MCBCL and to meeting other mandates, such as those associated with the ESA. An assessment of current and projected changes in nutrient loading from atmospheric deposition is a vital component to understanding the sensitivities of the MCBCL ecosystem to different stressors. This understanding will assist in the successful replacement of existing tree species with those common to native forest ecosystems, as well as the protection and enhancement of current and future generations of federally protected species and other species at-risk found within the confines of the Base.

2. Protection of nutrient-sensitive waters, wetlands, and coastal barrier islands from atmospheric deposition impacts. Atmospheric deposition (both wet and dry) represents the dominant source of new nitrogen (inorganic and organic nitrogen species) into the terrestrial and aquatic ecosystems of MCBCL. Local influences, and national trends in nitrogen emissions to the atmosphere suggest that nitrogen-loading may continue to increase with time at MCBCL, having a direct impact on the sustainability of the terrestrial and aquatic ecosystems.

Except for nitrogen-fixation by native plant species, inputs from migrating wildlife, and nutrient release from soil weathering, atmospheric deposition represents the only source of new nutrients into the terrestrial ecosystems at MCBCL. Research Project Air-2 will supply needed information to determine the amount, composition, and frequency of atmospheric inputs to assess the importance of atmospheric deposition on the sustainability of current terrestrial ecosystems and to determine long-term sustainability in regards to native flora and fauna, as well as the training mission of MCBCL.

Atmospheric deposition can also represent a significant percentage (20% to 50%) of new nutrients introduced into the aquatic/coastal barrier ecosystems being investigated at MCBCL (Paerl et al., 2002). Knowledge of the composition of atmospheric inputs is particularly important to assess sustainability. Research Project Air-2 will provide an estimate of the nutrient loading from atmospheric deposition to the forest floor/soil of terrestrial ecosystems that drain into the New River and associated coastal wetlands. This information is necessary to complete an assessment of whether and to what extent terrestrial ecosystems export nutrients to surrounding aquatic ecosystems, especially after implementation of current management practices such as PB, or from current and potential increases in hard surfaces within the confines of MCBCL. Results from this project will also provide a measure of the amount of organic nitrogen present in wet deposition at MCBCL.

The degree of atmospheric inputs to coastal barrier and coastal wetland ecosystems may be markedly enhanced by the presence of marine aerosols. Besides obtaining estimates of wet deposition, Research Project Air-2's integrated measurements of gaseous ammonia and nitrogen dioxide using passive

samplers across MCBCL will estimate whether there is a significant gradient for these gaseous components as a function of distance moving from Jacksonville to Onslow Beach. The presence of a significant gradient would support further research into the potential for enhanced deposition of nitrogen-containing species into the coastal barrier, coastal wetland, and estuarine ecosystems due to marine aerosols.

3. Protection of ecosystems from ozone and particulate matter (PM) pollution. Ozone, PM_{10}, $PM_{10-2.5}$, and $PM_{2.5}$ are regulated under the CAA-mandated National Ambient Air Quality Standards (NAAQS). Both pollutants are known to impact not only human health but also ecosystem components such as vegetation. EPA provides a comprehensive review of documented research on the impacts of $PM_{2.5}$ to various ecosystem communities (U.S. EPA, 2006).

Ozone can be formed in warm months from precursor anthropogenic and biogenic VOC and nitrogen oxide emissions. Fine particulates ($PM_{2.5}$) are either emitted directly as black carbon or inorganic dust or are formed as ammonium salts of ammonia and nitrates, sulfates, or chlorides (Ansari and Pandis, 1998). Nitrogen-based pollutants are commonly emitted as nitrogen oxides or ammonia from traditional stationary sources (e.g., coal-fired boilers), CAFOs, and mobile sources. The distance these pollutants travel depends not only on their physical/chemical character but also on atmospheric and meteorological conditions. Ammonia nitrogen's deposition velocity makes it more likely to deposit nearer its source (e.g., within 50 km), whereas ammonium, $PM_{2.5}$, and ozone can potentially transport longer distances.

The continued growth in North Carolina increased emissions of known precursors for ozone and $PM_{2.5}$. In October 2006, EPA revised the daily maximum ambient $PM_{2.5}$ standard from 65 to 35 $\mu g\text{-}m^{-3}$, effective December, 2006 (71 FR 61144). The nearest ambient $PM_{2.5}$ monitor operated by the State of North Carolina is located in Jacksonville, NC, approximately 1.5 miles north of MCBCL. A review of the data collected since 1999 indicates that if the new standard had been in effect, it would have been exceeded. MCBCL could benefit from its own ambient air monitoring data and a regional source apportionment to properly assess the contributions of off-site and on-site emission sources to regional levels of $PM_{2.5}$.

In preparing this DCERP Strategic Plan and the design of the DCERP Baseline Monitoring and Research plans, several years of historic air quality monitoring data in the region were reviewed. This review took place in the fall of 2006, during which time EPA revised the NAAQS for $PM_{2.5}$ (71 FR 61144). On a few occasions, the monitored ambient measurements indicated that if the revised standard had been in effect, ambient air quality would have exceeded the new standard. It is important to note that the region is currently in attainment with the 1997 $PM_{2.5}$ standard and that EPA will need to conduct a nationwide assessment before designating any areas in nonattainment with the new 2006 standard. A designation of nonattainment, in turn, requires State Implementation Plans to address the nonattainment designation. These plans may include measures to reduce regional mobile and/or stationary source emissions to bring the region back into attainment. The monitoring data were reviewed to gauge whether potential attainment issues might exist in the future that could impact MCBCL activities. The review was cursory; thus, the ambient measurements identified cannot be attributed to emissions from MCBCL activities. To establish the link to potential influences from simultaneous PB activities off the Base or indirect influences from post-burn smoldering from sources on MCBCL would require a detailed analysis, including local wind fields and HYSPLIT back trajectories, and/or post-analyses of sampled PM filters with application of receptor modeling for source apportionment.

Although no research projects are proposed to study the impacts of ozone and $PM_{2.5}$ on MCBCL ecosystem in the first four years of DCERP, these topics may be of interest in later years (particularly given the important role forestry plays in the MCBCL environmental management program).

Research Questions

The following research questions will address knowledge gaps in the conceptual model for the Atmospheric Module and provide answers to key management questions:

1. What are the current deposition levels of nitrogen-, carbon-, and sulfur-containing air pollutants to the terrestrial and aquatic ecosystems of MCBCL?
2. What are the predominant seasonal patterns in meteorology and air circulation across MCBCL?
3. How do PB activities redistribute nutrients?
4. What fraction of emissions from PB activities participates in sub-regional dispersion?
5. What are the amounts and composition of soil emissions following PB activities?
6. What are the contributions from local, regional (e.g., CAFOs), and continental sources to the nutrient and air pollutant input?
7. What are the mobile and stationary emission factors and profiles?
8. How does proximity to the open ocean influence aerosol formation and depositional patterns?
9. Does atmospheric ozone serve as a surrogate air quality indicator of ecosystem stress?
10. What is the degree and impact of mercury deposition (and redeposition following fire) on terrestrial and aquatic ecosystems?

7.6 Data Management Module

Ecological processes presented within each ecosystem module (Aquatic/Estuarine, Coastal Barrier, Coastal Wetlands, Terrestrial, and Atmospheric) link to processes in other modules. GIS-based ecosystem modeling will link transport mechanisms via air and water pathways among the modules. Ultimately, indicators from individual modules will be coupled with remote sensing to enable regional coverage. Data and information management systems are necessary to store, manage, and integrate data from each module so that cross-cutting, inter-module analysis and modeling can be performed.

Data integration, data sharing, and data management will be key functions of the DCERP data and information management systems, or simply referred to as the data systems. The types and volumes of baseline data that currently exist and that will be collected through DCERP are extensive. The Data Management Module will standardize input format of data across the other modules, such as date and time formats and standardization of measurement units for monitoring and research parameters.

To allow for the future development of integrated models and decision-support applications, the Data Management Module Team will work closely with Base management staff and research module teams to (1) identify and prioritize decision-support needs; (2) identify and prioritize opportunities for model integration; and (3) identify and prioritize opportunities to automate data processing and analysis workflows.

The purpose of the DCERP data and information management systems are to initially support the data management needs of DCERP and, ultimately, to support those of MCBCL's long-term, ecosystem-based data management. These computerized data systems will enable efficient, secure, and accurate input, analysis, integration, display, output, and sharing of data. In addition, they will enable broad data management functions necessary to support the complex IT environment, various end users, research collaboration, and complex and voluminous environmental data. These data systems will enable cross-cutting modeling, statistics, and decision-support applications. Per discussions with the SERDP management staff, the initial scope of the data systems will not include the development of integrative

models, remote-sensing processing, or decision-support applications, but will be specifically designed to allow for this functionality in the future. The implementation strategy of Goal 4 in Section 8.4, *Develop Ecosystem-based Management Tools*, discusses the development of ecosystem-based management tools in more detail.

The DCERP data and information management system consists of the following three distinct constituent systems:

- **Monitoring and Research Data Information System (MARDIS) for Structured Data.** MARDIS contains tabular and geospatial environmental monitoring data from each ecosystem module having defined content and structure that will be managed in a standard Relational Database Management System (RDBMS). MARDIS will be the long-term repository for DCERP monitoring and research data.
- **Document Database for Unstructured Data.** This database contains spreadsheets, SAS files, word processing documents, Web sites, reports, maps, and research publications that provide valuable information for DCERP, but that are not in a structured format suitable for an RDBMS. These files will be managed in a database and will be searchable via explicit metadata that describe the content of each file. Rather than storing and managing raw data (such as monitoring data), this database will store and manage documents.
- **DCERP Web Sites.**
  - **Collaborative Web Site:** The Collaborative Web site (http://dcerp.rti.org/private) is a place where DCERP Team members can share administrative planning documents, reports of activities, and other information of interest to their group and other DCERP Team members. It also includes a calendar for scheduling and managing field monitoring and research activities. This site is password protected and can only be viewed by the DCERP Team.
  - **Public Web Site:** The public Web site (http://dcerp.rti.org/) was designed to provide the general public with information about the program, including the mission statement for DCERP, as well as the background, objectives, approach, and benefits to MCBCL. Only documents, such as the DCERP fact sheet, which have been reviewed and approved by the researchers, MCBCL, and SERDP, are currently posted on the public Web site. The public Web site also contains contact information for SERDP staff, the DCERP PM, the DCERP OSC, the DCERP PI, and all DCERP module team members, as well as links to affiliated organizations.
  - The implementation strategy of Goal 5 in Section 8.5, *Information dissemination to interested parties*, discusses the dissemination of information, and the DCERP Web sites, in more detail.

8.0 Specific Goals and Implementation Strategies

This DCERP Strategic Plan identifies the specific goals and implementation strategies that will be used to achieve the overarching objectives of DCERP. These include (1) designing and implementing a baseline monitoring program, (2) designing and conducting a research program, (3) creating a data repository, (4) developing tools for MCBCL managers to use to apply ecosystem-based adaptive management, and (5) preparing information for dissemination in different forms via various media to diverse groups of interested parties.

As previously discussed, DCERP is designed to be implemented in two phases. Phase I of the program represents the planning period and includes the development of an overarching research strategy (DCERP Strategic Plan), design of an ecosystem-based monitoring program (DCERP Baseline Monitoring Plan), the identification of detailed research projects (DCERP Research Plan), and design a data and information management system. The final documents from Phase I will be presented to the Science Advisory Board

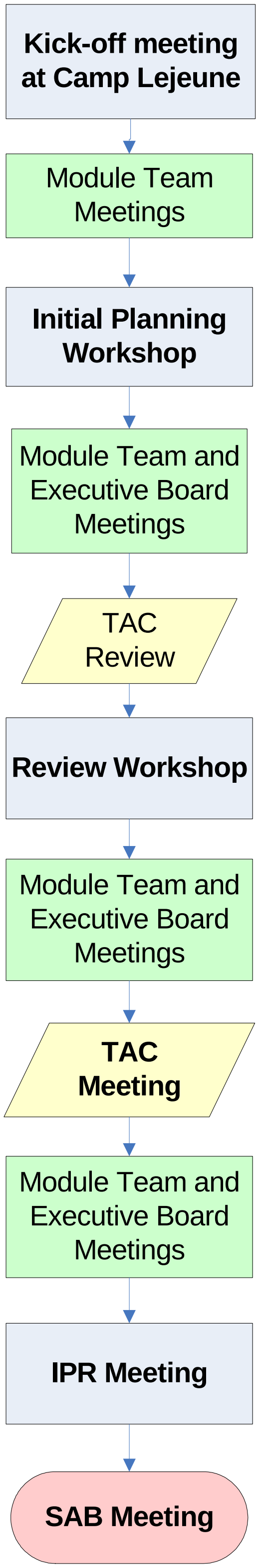
(SAB) for approval before proceeding to Phase II. Phase II of DCERP represents the program's implementation period and includes the execution of the DCERP Research Plan through field research; operation of the long-term ecosystem monitoring; and collection, management, and archiving of data from both of the research and monitoring components in MARDIS.

The Phase I planning period for DCERP was conducted between November 2006 and June 2007. This planning phase consisted of four, multi-day team workshops, as well as numerous smaller group meetings and conference calls as illustrated in **Figure 8-1**. The three planning documents that resulted from this effort were extensively reviewed by SERDP and the entire team prior to submission to the DCERP TAC for review. Comments from the TAC and SERDP SAB were incorporated into the Phase I planning documents before these documents were finalized.

The Phase II implementation period started in July 2007 and will last for a minimum of 4 years. Included within the Phase II implementation period will be periodic meetings with MCBCL and the TAC, as well as annual reviews by SERDP's Technical Committee for Sustainable Infrastructure and the SAB. Specific go/no-go decision points will be defined and evaluated on an annual basis.

Determining appropriate management decisions about military activities requires an understanding of all stressors affecting the environment, an assessment of the site-specific impact of those stressors, and an evaluation of their contribution to site degradation. Although it is understood that many factors can contribute to site-specific military impacts (e.g., frequency and intensity of training, physical characteristics of the site, meteorological conditions, legacy impacts), a consistent, quantitative evaluation methodology appropriate for MCBCL is not currently available. During Year 1 of Phase II, the RTI DCERP Team will implement a combined research and monitoring effort that will develop a consistent approach for assessing the impact of military training for each of the ecosystems at MCBCL. Assessments will occur at two scales: landscape and plot level.

Specific goals and implementation strategies will be discussed in this section. It is the responsibility of the DCERP PI to submit quarterly and annual reports, as well as a final report, to SERDP to ensure that these goals are achieved. The activities of DECRP will be reviewed annually by the SAB.



Step 1: The objectives of this meeting were to introduce the DCERP team to the staff from Camp Lejeune and SERDP. This meeting provided an opportunity for Camp Lejeune and SERDP to communicate their priorities and to present the DCERP approach. The meeting concluded with a tour of Camp Lejeune.

Step 2: Module teams incorporated military priorities identified during Step 1 and developed a draft conceptual model and overarching Strategic Plan.

Step 3: Module teams present module-specifc conceptual models and teams determine linkages among modules.

Step 4: Module teams present revised conceptual models, finalize draft Strategic Plan, begin development of module-specific monitoring plans, and identify tentative research projects based on information gaps in the conceptual models and identified needs of the base. Module teams submit data needs and storage requirements for data repository.

Step 5: TAC reviews Strategic Plan.

Step 6: Module teams identify changes to the Strategic Plan based on TAC comments. Teams present draft, module-specific baseline monitoring plans and prioritized research projects based on the Strategic Plan.

Step 7: Module teams revise individual monitoring and research plans and integrate into baseline monitoring and research plans. Teams finalize Strategic Plan and project website is implemented.

Step 8: TAC and module teams meet to review Baseline Monitoring and Research Plans and prepare for in-progress review (IPR) and scientific advisory board (SAB) meetings.

Step 9: Module teams revise and finalize Baseline Monitoring and Research Plans based on TAC comments. DCERP PI prepare presentations for the IPR and the SAB.

Step 10: DCERP PI briefs SERDP on the development of the Strategic Plan, Baseline Monitoring Plan, and Research Plan.

Step 11: DCERP presentation of Strategic Plan, Baseline Monitoring Plan, and Research Plan to SAB.

Figure 8-1. Phase I implementation process.

8.1 Goal 1 – Design and implement a baseline monitoring program

For the purposes of DCERP, baseline monitoring includes the monitoring of (1) basic (fundamental) parameters that support the broader research agenda, (2) parameters that provide data that are useful to more than one ecosystem module, (3) parameters that need to be monitored for a long time (5–10 years), and (4) parameters that will likely be transitioned in a scaled-down form to MCBCL to monitor directly at the end of DCERP efforts. The Baseline Monitoring Program is described in detail in the DCERP Baseline Monitoring Plan and will accomplish the following:

- Quantitatively characterize levels and variations in key environmental drivers (i.e., ecological processes and stressors), including both natural and anthropogenic drivers, and the status of essential physical, chemical, and biological components of each ecosystem module (e.g., Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and Atmospheric)
- Integrate and synthesize the preceding environmental and biological measurements into an interdisciplinary understanding of processes that are driving ecosystem dynamics and their impacts on ecosystem components
- Incorporate a clear understanding and characterization of MCBCL operations, information needs, and specific management issues
- Identify clear monitoring objectives that respond to explicit management objectives or understanding of ecosystem functions and questions
- Based on the monitoring objectives, identify appropriate environmental variables that can be sampled and translated into indicators, metrics, and ecosystem performance standards
- Follow a hierarchical approach such that measurements of key variables are made on a variety of spatial and temporal scales to allow inferences in relationships between ecosystem components and organizing processes between scales and rigorous extrapolation and interpolation for cost efficiencies
- Include appropriate quality assurance/quality control procedures
- Incorporate feedback loops to test the consequences of management or operational changes in the context of adaptive monitoring by modifying the underlying models accordingly
- Be designed to be transitioned into a long-term, Base-operated monitoring plan that can be shown to adequately predict the status of the broader elements of the system monitored by DCERP
- Ensure a consistent approach to data collection for those environmental variables that could be subject to different data collection methodologies and metrics. Incorporate periodic assessment of monitoring data that are collected to ensure that what is collected remains relevant and to enable any needed adjustments to the DCERP Baseline Monitoring Plan.

Implementation Strategy for Goal 1

The RTI DCERP Team implemented a baseline monitoring program using the iterative process described below, whereby each module’s baseline monitoring activities were discussed and reviewed among the scientific specialists on each of the individual module teams. The Module Team Leader and Co-leader convened members of their respective ecosystem module teams to discuss the conceptual model for their respective module and to review and analyze existing historic data. To ensure that the monitoring activities were developed based on a solid understanding of the existing ecosystem, each module team evaluated existing maps and had an opportunity to conduct preliminary field observations at MCBCL. It is also important to note that the module teams contacted colleagues and scoured Base records, information identified by SERDP on research in similar ecosystems, and scientific literature to assemble all current environmental information so that their understanding was based on state, county, and locally collected environmental data.

At the Initial Planning Workshop, the Module Team Leaders determined what GIS maps of MCBCL would be helpful to their monitoring and research planning efforts. As required, user-friendly GIS maps of essential baseline information were developed (if they did not currently exist) to assist in monitoring station site selection. Prior to initiating field monitoring activities, essential baseline data will be collected, compiled, analyzed, and archived to ensure appropriate sampling strategies and positioning of focus sites and to establish a starting point from which future changes in the environment can be assessed.

Following the Initial Planning Workshop, the Module Team Leaders conferred with their module teams to obtain and analyze more detailed information to fill existing data gaps and to assist in the development of their module-specific baseline monitoring activities. These monitoring activities address temporal and spatial considerations, as well as selected environmental indicators. The module teams presented plans for the baseline monitoring activities at a second workshop (the Review Workshop) and these plans were reviewed by SERDP, MCBCL staff, and the RTI DCERP Team. Based on the discussions and review comments obtained from the Workshop, the Module Team Leaders worked with their teams to revise these baseline monitoring activities, as necessary. The Executive Board, along with team member participation, integrated the module-specific monitoring activities into the DCERP Baseline Monitoring Plan, which addresses the highest-priority needs of all of the individual modules and the overall goals of DCERP. The integrated DCERP Baseline Monitoring Plan was sent to the TAC for review. Review comments received from the TAC were addressed by the PI, with technical assistance from the Module Team Leaders and Co-Leaders. The RTI DCERP Team finalized the draft DCERP Baseline Monitoring Plans in preparation for review by the SAB.

8.2 Goal 2 – Design and implement a research program

The RTI DCERP Team has designed and will implement a research program that increases the knowledge base and understanding of MCBCL-relevant ecosystem functioning, stressors, and system responses to stresses and management actions. The overall research program is comprised of 13 separate research projects that

- In combination, increase our understanding of overall ecosystem function for those ecosystems present at MCBCL
- Build upon an existing knowledge base, including previously conducted research by other scientists, collaboration with other ongoing MCBCL-funded research or monitoring efforts, and other projects funded by SERDP or separate funding programs
- Yield definitive results within a predefined timeframe and budget
- Include focused studies designed to fill existing gaps in understanding of processes that may have critical influence on the status and dynamics of the ecosystem
- Produce explicit answers to management questions and challenges identified by MCBCL environmental managers
- Provide a durable legacy of the basic scientific understanding of MCBCL and other analogous ecosystems and of ecosystem-based management responses that could impact environmental sustainability.

Implementation Strategy for Goal 2

Each of the DCERP module teams designed research projects that answer specific research questions identified in their conceptual model. The research projects for each module were developed using the iterative process described below, whereby each module's research projects were discussed and reviewed among the scientific specialists on each of the individual module teams. Each module team developed and prioritized a preliminary set of research projects (with the primary objectives of filling information gaps in the conceptual models and providing data to support Base management needs and priorities) for presentation and review by attendees at the Review Workshop. It is important to note that the module

teams used MCBCL records, information identified by SERDP on research in similar ecosystems, and scientific literature and contacted colleagues to identify and assemble all historic and current environmental data related to the module. Research projects were developed to address specific questions and fill data needs that will assist in "adapting" the DCERP Baseline Monitoring Plan as new information becomes available.

During the Review Workshop, the combined module research projects were prioritized based on their immediate importance in addressing module information needs, whether they were linked to information needs of other research projects or of other modules, and whether they specifically addressed the management needs presented by MCBCL. Following the Review Workshop, the highest-priority preliminary research projects were further refined by each module team based on reviewer comments. The Executive Board, along with team member participation (as necessary), integrated the revised individual plans into a single DCERP Research Plan, addressing the highest-priority needs of all of the individual modules and the overall goals of DCERP. The overall, integrated DCERP Research Plan includes a schedule for phasing in the highest-priority research projects in a timely manner throughout the duration of the DCERP contract. The final draft DCERP Research Plan was submitted to the TAC for review. Comments received from the TAC were addressed by the RTI PI, with technical assistance from the Module Team Leaders and Co-leaders. RTI and the Module Team Leaders and Co-leaders finalized the DCERP Research Plan in preparation for review by the SAB.

8.3 Goal 3 – Develop a data and information management system

DCERP will involve the creation of a research environment that will require multimedia monitoring/data collection and research collaboration. Data integration, data sharing, and data management will be key to the development of this environment and to the success of DCERP. The types and volumes of baseline data that currently exist and that will be collected through DCERP monitoring and research activities are extensive. Data types include the following:

- Spatial data (e.g., raster and vector)
- Tabular environmental monitoring data having extensive and complex data management needs with links to a geospatial location (e.g., water quality data, meteorological data)
- Non-spatial data (e.g., reports, graphs, analytical outputs, management tools, peer-reviewed journal articles).

The purpose of the DCERP data and information management system is to initially support the data management needs of DCERP and, ultimately, to support those of MCBCL's long-term, ecosystem-based data management. These computerized data systems will enable efficient, secure, and accurate input, analysis, integration, display, output, and sharing, as well as the broad data management functions necessary to support the complex information technology environment, various end users, research collaboration, and complex and voluminous environmental data to be collected and used to support DCERP.

The DCERP data and information management system must include the following:

- Data management functions inherent in Relational Database Management Systems
- Web-based access
- Interfaces allowing research and MCBCL user communities to draw data from the repository to drive modeling and decision-support systems.

Implementation Strategy for Goal 3

A software development process is a structure imposed on the development of any software product. This process is often referred to as software lifecycle or as software lifecycle management (LCM). Because of the complexity of the proposed data and information management systems, it is essential to choose a software development process that allows the system development to progress in an orderly, defined fashion. This will result in a system that meets the needs of its users and is developed within budget and time constraints.

The standard LCM processes of program definition, requirements gathering, preliminary system design, detailed design, development, implementation, operations, and transfer/close-out will be followed in the development of the DCERP data and information management system. In addition, the RTI DCERP Team will include procedures for the design and implementation of some features using an iterative, phased approach. Interim and shorter-term functions and capabilities will be periodically rolled out to provide necessary functions to researchers and the end-user community. The interim, phased, and short-term functions will also be described, documented, and selected using the basic LCM approach prior to being developed. Test plans will be developed, and unit, integration, and system testing will be completed for each new module or function added to the system.

The end users of the DCERP data and information management system will drive decisions regarding functions, operating environment, development, and priorities. Because the data and information management system must, ultimately, satisfy the stakeholders' needs, stakeholders will be key players in the design and development of the system, and the design process will include periodic and extensive contact and communication with these groups. Decisions affecting how end users interact with the system must be made in collaboration with those users. Appropriate data developed as part of DCERP will be transitioned to MCBCL. Some data may not be transitioned to the Base, but may have inherent scientific value and may be used in publications or in the development of models that would be transitioned to the Base. Some data may be of regional interest and be transitioned to an appropriate host organization that can maintain and even add to this data.

8.4 Goal 4 – Develop ecosystem-based management tools

An ultimate goal of DCERP is to develop tools to enable MCBCL managers to identify adaptive, ecosystem-based management approaches. These tools will include models to forecast the impacts of military activities and other stressors and indicators to assess healthy, transitional, or degraded conditions. The scale and complexity of these tools will depend on the needs of MCBCL and the level of funding available to the program. As the DCERP ecosystem research and monitoring strategy is implemented, the need to develop analytical workflow systems and decision-support tools to automate the processing of raw monitoring data into useful management information will increase. These tools will enable MCBCL managers to make informed decisions to support their long-term goals of military training and preparedness.

Implementation Strategy for Goal 4

In the initial phase of this effort (estimated to take place in Year 2 of Phase II of DCERP), the RTI DCERP Team will work with MCBCL staff to identify and prioritize opportunities for the development of automated workflow processes, integrated models, and new decision-support tools. Because this process will necessarily be driven by emerging end-user needs at MCBCL and the data products and models yet to be developed by DCERP, it is difficult to directly anticipate and prioritize the specific models and tools that will be needed at this time. Planning for the future development and implementation of these end-user tools will require a focused planning and evaluation effort to identify and prioritize this work as DCERP evolves and matures. The integrated modeling, workflow automation, and decision-support tool development planning effort will (1) identify and prioritize tool development with MCBCL

and DCERP users; (2) identify robust, modular, and sustainable software systems for implementation; (3) identify data and software protocols and best-practices to enhance automation and interoperability; (4) evaluate infrastructure, data, and training needs for implementation; and (5) develop a proposed timeline for implementation. These efforts will be conducted in close coordination with the DCERP data and information management system development, and outcomes of these efforts will be used to refine the information system architecture of DCERP. Full implementation of automated data analysis systems, integrated models, and decision-support tools identified by this process will then be proposed for funding through the DCERP effort or a separate funding arrangement, if appropriate.

Some modeling tools will be developed by module teams that integrate information from other modules to answer specific management objectives. These tools will provide a starting point for the development of a fully automated decision-support system. For example, the Aquatic/Estuarine Module Team will develop models of geochemical fluxes and aquatic ecosystem dynamics and a Bayesian model of water quality degradation in the NRE as a function of regional and local stressors. The Coastal Barrier Module Team will develop models of how geological base, bathymetry, and storm waves influence site-specific erosion of Onslow Island shorelines.

8.5 Goal 5 – Information dissemination to interested parties

It is anticipated that DCERP will generate a significant amount of environmental data and research findings; therefore, a goal of DCERP is to design and develop information for dissemination to the scientific community, natural resources managers, and the general public through outreach materials.

Implementation Strategy for Goal 5

RTI DCERP Team members all have extensive experience in disseminating scientific and management information to a wide spectrum of audiences and through diverse communications media. A regular flow of professional basic scientific and management-oriented publications is expected from all team members, beginning within two years of initiation of the monitoring and research phase of this program. These papers will be provided to the DCERP PI, the DCERP PM, SERDP, and the MCBCL Director of the Environmental Management Division for initial review, then submitted to and ultimately published in high-impact, peer-reviewed scientific journals. From the past productivity of the scientists assembled for this program, this flow of information is likely to be both regular and strong. In addition, chapters contributed to edited and peer-reviewed scientific books will likely be vehicles for the dissemination of printed results of monitoring and research studies.

The research scientists that comprise the RTI DCERP Team also participate in meetings of scientific societies, scientific conferences, and in special *ad hoc* symposia at which verbal presentations of new results are made. We anticipate this process will serve to provide even more rapid dissemination of results from this program than print publications. Presentations will also be made regularly at SERDP meetings.

During Phase II implementation, the RTI DCERP Team will provide quarterly reports and briefing updates (as desired) to MCBCL natural resources management staff. These reports will summarize the progress and results of monitoring and research in each module and facilitate feedback from MCBCL staff, thereby strengthening the link between the RTI DCERP Team and MCBCL. In addition to these reports, the RTI DCERP Team will provide relevant information to natural resources and environmental managers in special forums, including public information sessions relating to environmental issues in which the Base has a stake. Such presentations will be carefully reviewed by the DCERP PI, the DCERP PM, SERDP, and MCBCL staff in advance, following the guidelines included in the DCERP Memorandum of Agreement.

Two DCERP Web sites also were established during the first six months of the program: the public Web site and the private Collaborative Web site. The public Web site is designed to provide the general public with information about DCERP, including the mission statement, as well as the background, objectives, approach, and benefits to MCBCL. Documents, such as the DCERP fact sheet, which are approved and are in final form, will be made available to the general public via the public Web site. This Web site also contains contact information for SERDP staff, the DCERP PM, the DCERP OSC, the DCERP PI, and DCERP Module Team Leaders and Co-leaders, as well as links to affiliated organizations. Although the public Web site allows the general public to download approved documents, it is a static site with no collaborative or interactive functions.

In contrast to the public Web site, the private Collaborative Web site facilitates the sharing of information and documents between members of the DCERP Team. This site is password protected and can only be viewed by the DCERP Team. The private Collaborative Web site was developed to provide a tool to allow the DCERP Team to collaborate early on and throughout the program. The Web site is a Web-based portal that allows the DCERP Team to share information, review documents, and learn about upcoming program events/activities. The Collaborative Web site provides a space for the DCERP Team to collaborate on document review, as well as a location for project management, documents, maps, timelines, scheduling, and data sharing.

9.0 Measurement of Success

The successful implementation of DCERP will foster a greater understanding of the biologically diverse aquatic/estuarine, coastal wetland, coastal barrier, and terrestrial ecosystems of MCBCL; the Base's air quality; and the interactions of these systems with military training activities. This understanding will aid in the long-term management and sustainability of MCBCL ecosystems, which will enhance and maintain MCBCL's military mission. Information and data resulting from the DCERP research and monitoring efforts will increase the ability of resource managers to perform assessments and implement appropriate management responses to potential environmental impacts arising from military activities or natural disturbance events. In addition, DCERP's monitoring metrics and techniques likely will be transferable to other DoD installations in ecologically similar settings.

Measurement of DCERP's success will come from assessing whether the outcomes are produced in a timely manner and the desired outcomes achieved. The outcomes defined for DCERP can be grouped into two main categories:

- Programmatic—includes administrative requirements, such as delivering required documents on schedule and on budget, ensuring that the project Web sites are developed and functioning, meeting SERDP quarterly and annual reporting requirements, and providing timely and effective feedback to MCBCL and outreach to stakeholders. **Table 9-1** provides a list and delivery schedule for currently anticipated programmatic products/outcomes.
- Project specific—includes those outcomes identified in the DCERP Baseline Monitoring Plan and DCERP Research Plan. In some cases, these outcomes provide information to address environmental issues that are currently impacting Base operations. Other research and monitoring efforts were designed to provide outcomes relevant to issues that are currently known, and that are anticipated to impact Base operations in the next 3–5 years. In addition, the majority of the DCERP research and monitoring activities will provide information necessary to gain a complete understanding of ecosystem functions, which will better prepare the Base to address future environmental issues.

Table 9-1. Timeline for Programmatic Products/Outcomes

Product/Activity/Outcome	Due Date
Project Web Sites—A secure site to facilitate information sharing among DCERP Team members and MCBCL, and a public site to provide information to other stakeholders and the general public.	March 2007
Final Strategic Plan—Communicate overall DCERP strategy to the Team and other groups.	June 2007
Final Baseline Monitoring Plan—Document activities included in the monitoring program.	June 2007
Final Research Project Plan—Describe the research projects that will be implemented in the Phase II implementation period.	June 2007
Design of the data and information management system—Provide the overall description of the DCERP data and information management system.	June 2007
Semi-annual Progress Reports and Meetings with MCBCL—Ensure ongoing awareness of activities and facilitate collaboration.	Beginning September 2007
SERDP Annual Report and Conference Participation—Provide official summary of annual activities for SERDP recordkeeping; provide an opportunity for outreach and collaboration with other researchers.	Beginning December 2007
Functional data and information management system—Support the data management needs of DCERP and ultimately support those of MCBCL's long-term, ecosystem-based data management.	Beginning January 2008
Peer Reviewed Journal Articles—Provide outreach of key scientific results to other researchers.	Beginning September 2009
Interim Transition Plan for Base—Provide Base personnel the information they need to implement results from DCERP and to continue operating a scaled-down monitoring program.	3–6 months prior to contract completion (June 2011 or later, depending on project duration)

MCBCL has identified several high-priority, strategically important outcomes that they would like to result from DCERP. The design of the research and monitoring programs has taken these into account and will seek to address each of the following outcomes:

- To support the outcome of *compliance with the Clean Water Act*: DCERP will provide data on water quality impacts resulting from local (Base activities) versus regional (outside of the Base) stressors, along with indicators and other thresholds of declining water quality.
- To support the outcome of *no net loss of wetlands*: DCERP will identify wetland areas undergoing significant erosion along with the relevant contribution of military activities to that erosion, as well as management alternatives for mitigating wetland degradation resulting from training activities.
- To support the outcome of *maintaining the extent and ability to conduct military maneuvers on Onslow Beach*: DCERP will identify the underlying causes of accelerating beach erosion, as well as the ability to project the rate of beach erosion that could result following the implementation of a variety of management actions.
- To support the outcome of *compliance with the CAA and NAAQS regulation and the development of a Smoke Management Plan*: DCERP will quantify air emissions from the Base's PB program

and provide the Base with the ability to more accurately forecast air emissions resulting from different management scenarios.

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Appendix A

State and Federal Regulations*
Summarized May 2007

* Note: This appendix contains a summary of regulations that may impact MCBCL and should be considered as general guidance for background information only.

1. Introduction

Marine Corps Base Camp Lejeune (MCBCL) must achieve its mission to provide military training while complying with applicable federal and state regulations. Many of these regulations are captured in MCBCL's natural resources management objectives, as described in the *Integrated Natural Resources Management Plan* (INRMP) (MCBCL, 2006a):

1. Preserve the integrity of the amphibious maneuver areas, including Onslow Bay, the New River Estuary (NRE), and the adjoining training areas and airspace of MCBCL.
2. Preserve the integrity of MCBCL as a combined-arms training base by ensuring the continued viability of its impact areas and associated training ranges.
3. Enhance future training uses of MCBCL ranges, training areas, and airspace by fully integrating the *Land Use Master Plan* (MCBCL, 2005) and *Range Transformation Plan* (MCBCL, 2006b).
4. Ensure that MCBCL supports all required military training activities while complying with the Endangered Species Act (ESA) and other wildlife requirements.
5. Ensure that MCBCL supports continued military training use of the New River, the NRE, and Onslow Bay by complying with the Clean Water Act (CWA).
6. Ensure the viability of the New River Air Station as an aviation facility through the elimination of bird and wildlife strike hazards to aircraft while complying with the ESA and other wildlife regulatory requirements.

The following sections provide a summary of the regulations and, where applicable, how MCBCL is managing for compliance with these regulations.

2. Clean Air Act

2.1 Regulatory Background

Under the authority of the federal Clean Air Act (CAA), passed in 1970 and amended in 1990, the U.S. Environmental Protection Agency (EPA) sets standards, or criteria, for six pollutants that are deemed harmful to human health and the environment. These "criteria pollutants" are ground-level ozone, particulate matter (PM), nitrogen dioxide, sulfur dioxide, lead, and carbon monoxide. The EPA's primary standards protect human health, and secondary standards for some pollutants protect public welfare and the environment. The North Carolina Division of Air Quality (NCDAQ) implements these federal standards. Currently, North Carolina is meeting the federal standards for four criteria pollutants: nitrogen dioxide, sulfur dioxide, lead, and carbon monoxide; however, several urban areas in North Carolina are violating the ground-level ozone standard and the $PM_{2.5}$ annual standard.

2.1.1 Ozone

Ozone, an extremely reactive form of oxygen, is the main component of smog. In the upper atmosphere, ozone protects the earth from harmful solar radiation. Near the ground, however, ozone is unhealthy to breathe, damages trees and crops, and can degrade outdoor materials. Such problems led EPA to adopt stricter standards for ozone levels in 1997 (Table 2-1). Ozone is formed when nitrogen oxide reacts in the air with volatile organic compounds (VOCs) on hot, sunny days. The main sources of nitrogen oxide emissions are cars and trucks, coal-fired electric power plants, and large industrial boilers. Trees are the major source of VOCs in North Carolina, but substantial emissions also come from industry and motor vehicles. Ozone levels have risen in recent years due to increased traffic and industry resulting from North Carolina's rapid population growth and hotter weather conditions that favor ozone formation. The

State of North Carolina is working to reduce ozone levels by reducing emissions from industry and motor vehicles (http://daq.state.nc.us/news/brochures/clearair.shtml).

Table 2-1. National Ambient Air Quality Standards for Ground-Level Ozone

Pollutant	Primary Standards	Averaging Times	Secondary Standards
Ozone	0.08 ppm	8-hour [1]	0.08 ppm
	0.12 ppm	1-hour [2] (Applies only in limited areas)	0.12 ppm

[1] To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

[2] (a) The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is $\leq$ 1.

(b) As of June 15, 2005, EPA revoked the 1-hour ozone standard in all areas except the fourteen 8-hour ozone non-attainment Early Action Compact areas.

Source: NC DENR/DAQ

On June 21, 2007, the U.S. Environmental Protection Agecy (EPA) proposed to revise the "secondary" standard for ozone to improve protection for plants, trees, and crops during the growing season. The secondary standard is based on scientific evidence indicating that exposure to even low levels of ozone can damage vegetation. EPA is proposing two alternatives for this standard: a standard that would be identical to the "primary" 8-hour stand to protect human health, i.e. reducing it from 0.08 ppm to a level between 0.070 and 0.075 ppm, and a cumulative standard aimed at protecting vegetation during the growing season (EPA 40 CFR Part 50, EPA_HQ_OAR-2005-0172).

2.1.2 Fine Particulates

Fine particulates are very small particles of dust, soot, and vapors that can penetrate deep into a person's lungs and cause health problems. In 1997, EPA adopted a new standard for fine particulates, or $PM_{2.5}$. The State of North Carolina began monitoring the air for fine particulates in 1999 and is developing plans for reducing these emissions (NCDAQ, 2002).

The ambient air quality standards for $PM_{2.5}$ are: (1) 15.0 micrograms per cubic meter ($\mu g/m^3$), annual arithmetic mean concentration (62FR 38652, July 18, 1997), and (2) 35 $\mu g/m^3$, 24-hour average concentration (71 FR 61144, October 17, 2006). Designated $PM_{2.5}$ non-attainment areas for the annual standard of 15 $\mu g/m^3$ in North Carolina are Davidson County, Guilford County, and Catawba County (NCDAQ, 2002).

2.1.3 Haze

Haze can be caused by various air pollutants that reduce visibility, including dust, ammonia, and sulfur oxides. Visibility has important implications for the state's tourist economy because haze can obscure views and detract from scenery—a critical issue in the mountains. The NCDAQ is working with power plants to reduce emissions of sulfur oxides, the single most important cause of haze in North Carolina (NCDAQ, 2002). In 2006, the State of North Carolina adopted Best Available Retrofit Technology (BART) standards aimed at reducing haze-forming emissions from stationary sources deemed within impact range of North Carolina's pristine national parks or wilderness areas designated as Class I areas (i.e., fall under the prevention of significant deterioration program).

Smoke from outdoor burning pollutes the air and is unhealthy to breathe. An EPA study found that backyard burning of trash from a family of four can emit as much pollution as a well-controlled municipal

incinerator serving tens of thousands of households. Open burning is the NCDAQ's most widespread enforcement problem. The North Carolina open-burning rule prohibits most outdoor burning, with exceptions allowed for campfires, land-clearing under certain conditions, the disposal of vegetative storm debris, and agricultural pest control (NCDAQ, 2002).

2.2 Smoke Management Plan

In 2007, the State of North Carolina proposed air quality regulations requiring Smoke Management Plans for prescribed burns. The purpose of a Smoke Management Plan is to manage smoke from prescribed burns of public and private forests to minimize the impact of smoke on air quality and visibility. [Source: 15A NCAC 02D .1902] These plans are developed following the North Carolina Division of Forest Resources' (NCDFR) Smoke Management Program and approved by the NCDFR.

The following open-burning activity conducted at MCBCL is permissible without an air quality permit: fires purposely set to public or private forest land for forest management practices for which burning is acceptable to the NCDFR and that follow a Smoke Management Plan, as outlined in the NCDFR's Smoke Management Program

2.3 Nutrient Deposition

Nutrient deposition is caused when air pollutants containing nitrogen and other nutrients settle in or are washed into streams, lakes, and coastal waters. Abundant levels of these nutrients can contribute to algal blooms and fish kills in these waters. Nitrogen deposition is the largest airborne nutrient problem in North Carolina, with most emissions coming from livestock operations, industry, and motor vehicles (NCDAQ, 2002). Table 5-1 highlights federal and state nitrogen-reduction actions.

Table 5-1. Historical and Projected Nitrogen Reductions from Air Quality Initiatives in North Carolina

Action	Year	Source(s)	Pollutant(s)	Description
State				
Ambient Air Quality Improvement Act	1999	Mobile		Required purchase of alternative fuel vehicles by state fleets; expanded motor vehicle emissions testing from 9 to 28 counties.
Nitrogen oxide emission rules	2001	Stationary	Nitrogen oxide	Utility emissions to drop 58% from 2000 to 2004 and 68% by 2006. Reductions also required at large industrial boilers, electric co-generation plants, and petroleum pipeline compressor stations.
Heavy-duty Diesel Engine Rule	2001	Mobile	Nitrogen oxide	Reduce emissions from heavy-duty diesel engines for model years 2005 and 2006 to address gap in federal standards.
Clean Smokestacks Act	2002	Coal-fired power	Nitrogen oxide	Fourteen plants must achieve a 77% cut in emissions by 2009.
Smithfield Settlement Agreement	2000	Swine	Ammonia	Development of environmentally superior alternatives to anaerobic lagoon and sprayfield system for swine waste. To reduce ammonia emissions.
Federal				
CAA Amendments Title IV	1996	Boilers stationary	Nitrogen oxide	The acid rain requirements incorporate a two-phased strategy Reductions were projected at 400k tons/year for 1996–1999 (Phase I) and over 2 million tons/year in 2000 and subsequent years (Phase II).

Action	Year	Source(s)	Pollutant(s)	Description
Nitrogen oxide SIP Call, Section 126 Petitions, Federal Implementation Plans (FIPS)	1998		Nitrogen oxide	Summer season emissions reductions for 22 states and the District of Columbia for targeted emissions sources, including a capped, market-based trading program for certain stationary sources.
New Source Performance Standards (NSPSs)		Stationary	Nitrogen oxide	To date, EPA has promulgated 10 NSPSs. For fossil fuel-fired utility and industrial boilers, these limits will reduce projected growth in emissions from new sources by ~42%.
New Source Review		Major stationary	Nitrogen oxide	In certain ozone and nitrogen oxide nonattainment areas/transport regions, require new/modified sources to offset increased emissions and install controls representing the lowest achievable emission rate (LAER) or install the best available control technology (BACT) (Adopted by North Carolina in 2005.)
Reasonably available control technology (RACT		Stationary	Nitrogen oxide	In certain ozone and nitrogen oxide nonattainment areas/transport regions, require existing sources to apply RACT
Clean Air Interstate Rule (CAIR)	2006		Nitrogen oxide	Permanently cap emissions in the eastern United States. When fully implemented, will reduce emissions by more than 60% from 2003 levels. (Adopted by North Carolina in 2006.)
Best Available Retrofit Technology (BART)	2006			Intended to improve visibility in Prevention of Significant Deterioration Class I areas. Could have a co-benefit of reducing PM_{fine} precursor nitrogen oxide. Areas include Swan Quarter National Wildlife Refuge. (Adopted by North Carolina in 2006.)
Tier I/Tier II tailpipe standards for light-duty vehicles/ trucks	2000	Mobile	Nitrogen oxide	Reduce emissions by 850,000 metric tons/year by 2010. Tier II tailpipe emission standards for sport utility vehicles (SUVs), minivans, and pickup trucks to meet the same protective standards as passenger cars, regardless of the type of fuel used. If finalized, will reduce emissions by an additional 2.8 million tons by 2030.
Low or no emission vehicle standards	2001	Mobile	Nitrogen oxide	Compliant model year 2001 and newer vehicles will meet California emission standards and will reduce nitrogen oxide emissions by 181,000 metric tons/year by 2007.
Clean Air Non-Road Diesel Rule	2004	Other mobile	Nitrogen oxide	Will reduce Nitrogen oxide by 738,000 tons annually

2.4 Mobile Sources of Air Pollution

North Carolina’s Inspection & Maintenance (I/M) Program is aimed at ensuring that pollution controls work properly on cars and trucks. The I/M Program focuses on the 48 counties for which motor vehicles contribute most significantly to air quality pollution by requiring annual inspections using onboard diagnostics to assess the potential for nitrogen oxide emissions. For example, highway emissions account for about one-third of the ozone-forming emissions statewide and up to 70% in larger urban counties. Onslow County, NC, where MCBCL is located, has been required to implement this program.

2.5 Air Toxics

Air toxics include a range of compounds that are hazardous, poisonous, or unhealthy to breathe at certain concentrations. North Carolina's Air Toxics Rules set health-based limits for 105 compounds the emissions sources are not to exceed. Permitting and emission controls are required for those sites where emissions are modeled to exceed these limits. The NCDAQ also enforces federal toxics rules that establish Maximum Achievable Control Technologies (MACTs), by industry groups, for sources that emit threshold quantities of 188 hazardous air pollutants (HAPs) (NCDAQ, 2002). It is understood that MCBCL handles some of these HAPs (NCDAQ, 2006).

2.6 Mercury

Mercury is a metal that can be toxic to humans if inhaled at high concentrations; however, the primary source of human exposure to mercury comes from the consumption of certain fish. Power plants are the largest source of mercury emissions in North Carolina due to the sheer volume of coal they burn to produce electricity. When coal is burned, it releases small amounts of mercury into the air. Some of the mercury falls into streams, lakes, and coastal waters, where it can accumulate to harmful levels in some fish. The North Carolina Division of Public Health issues advisories about limiting consumption of certain fish that can have elevated levels of mercury. These advisories apply to largemouth bass from waters throughout North Carolina and a number of other predatory fish from streams, lakes, and coastal waters across the state. Eating mercury-contaminated fish can be particularly harmful for children, pregnant and nursing women, and people who eat a lot of fish from affected waterbodies (NCDAQ, 2006).

Under current rules adopted by the North Carolina Environmental Management Commission (EMC), North Carolina's power plants must cut their mercury emissions substantially over the next 12 years or face being shut down. The EMC Clean Air Mercury Rules (CAMRs) require 14 coal-fired power plants to install controls for reducing mercury emissions that may have contributed to elevated levels of mercury in some fish from North Carolina waters. Ultimately, these rules could lead to nearly a 90% reduction in mercury emissions based on the levels of mercury contained in coal. The EMC CAMRs go beyond the federal CAMR. EPA estimates that the federal CAMR will reduce mercury emissions by about 20% in 2010 and 70% in 2018. Under the North Carolina CAMR, reductions in mercury emissions will meet or exceed the federal requirements on a faster timetable (NCDAQ, 2006).

3. Clean Water Act

3.1 Federal Overview

The CWA of 1972 is the cornerstone of surface water quality protection in the United States. The statute employs a variety of regulatory and nonregulatory tools to sharply reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff. These tools are employed to achieve the broader goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters so that they can support "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water."

To comply with the CWA, water quality standards consistent with the statutory goals of the CWA must be established. Waterbodies are monitored to determine whether water quality standards are met and, if all standards are met, antidegradation policies and programs and ambient monitoring are employed to keep the water quality at acceptable levels. If a waterbody is not meeting water quality standards, a strategy for meeting these standards must be developed. The most common type of strategy is the development of a Total Maximum Daily Load (TMDL). A TMDL determines the pollutant load to a

waterbody that would be consistent with meeting the applicable water quality standards and then allocates acceptable loads among sources of that pollutant.

3.2 CWA in North Carolina

Under the directive of the CWA, states are required to adopt water quality standards to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters. Surface water classifications are also established as another tool to manage water quality. The classification is known as the 'designated use' for that waterbody (mandated by Section 305(b) of the CWA). All surface waters in North Carolina are assigned a primary designate use classification by the North Carolina Division of Water Quality (NCDWQ) under the authority of the EMC. Specific numeric and narrative water quality standards are associated with each classification to protect its designated best use.

The North Carolina Surface Water Quality Standards are located in Title 15A of the North Carolina Administrative Code (NCAC). Section 15A NCAC 2B .0300 lists waterbodies and their associated classifications. Sections 15A NCAC 2B .0100 and 2B .0200 contain numeric and narrative surface water quality criteria and procedures for applying the water quality criteria to wastewater dischargers and other sources of pollution. Specific water quality criteria have been developed for each of the primary classifications for surface water quality used to designate waters within North Carolina. These numeric and narrative criteria are established at levels that will ensure the protection of the designated best use of the waterbody. Table 3-1 defines the designated use of all the waters within MCBCL.

Table 3-1. Designated Use Definitions for Surface Waters in North Carolina

Class C	Freshwater waterbodies protected for secondary recreation, fishing, aquatic life (including propagation and survival), and wildlife. All freshwater waterbodies shall be classified to protect these uses at a minimum.
Class B	Freshwater waterbodies protected for primary recreation, which includes swimming on a frequent or organized basis and all Class C uses.
Class SC	Saltwater waterbodies protected for aquatic life propagation and maintenance of biological integrity, including fishing, fish, functioning primary nursery areas (PNAs), wildlife, secondary recreation, and any other usage except primary recreation or shellfishing for market purposes.
Class SB	Saltwater waterbodies protected for primary recreation (which includes swimming on a frequent or organized basis) and any other usage specified for Class SC waters.
Class SA	Saltwater waterbodies protected for shellfishing for market purposes and any other usage specified for Class SB or SC waters.
High Quality Waters (HQW)	Waterbodies that are rated as excellent based on biological and physical/chemical characteristics through NCDWQ monitoring or special studies; native and special native trout waters (and their tributaries) designated by the North Carolina Wildlife Resources Commission; PNAs designated by the North Carolina Marine Fisheries Commission (NCMFC); and other functional nursery areas designed by the NCMFC.
Nutrient-Sensitive Waters (NSW)	Waterbodies that experience or are subject to excessive growths of microscopic or macroscopic vegetation requiring limitations on nutrient inputs.

Source: 15A NCAC 02B .0101(c-e)

3.3 Total Maximum Daily Loads (TMDLs)

Section 303(d) of the CWA requires states to identify and establish a priority ranking for waterbodies for which technology-based effluent limitations required by Section 301 of the CWA are not stringent enough to attain and maintain applicable water quality standards; establish TMDLs for the pollutants causing impairment in those waterbodies; and submit a list of impaired waterbodies and TMDLs to EPA. Current federal rules require states to submit 303(d) lists biennially (by April 1st of every even numbered year). A

TMDL must be developed for each waterbody impaired by a pollutant and is identified on the §303(d) list,. TMDLs are not required for waters not impaired by pollutants. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards and an allocation of that amount to the pollutant's sources.

The *North Carolina Water Quality Assessment and Impaired Waters List* is an integrated report that includes both the 305(b) and 303(d) reports of previous years. Table 3-2 is a list of all impaired waters within MCBCL's watershed based on the State of North Carolina's 2006 Integrated Report to EPA (NCDWQ, 2006).

Table 3-2. MCBCL's List of Impaired Streams

Waterbody	AU	Class[1]	USGS HUC	Reason for Listing
Southwest Creek	19-17-(6.5)	C HQW NSW	30502	Chlorophyll-*a*
Mill Creek	19-30-1	SA	30502	Fecal coliform
Muddy Creek	19-30-2	SA	30502	Fecal coliform
Stones Creek	19-30-3	SA	30502	Fecal coliform
Millstone Creek	19-30-3-1	SA	30502	Fecal coliform
Everett Creek	19-32	SA	30502	Fecal coliform
Holover Creek	19-41-3-1	SA	30502	Fecal coliform
Gillets Creek	19-41-4	SA	30502	Fecal coliform
Freeman Creek	19-41-5	SA	30502	Fecal coliform
Browns Swamp	19-41-5-1	SA	30502	Fecal coliform
Clay Bank Branch	19-41-5-2	SA	30502	Fecal coliform
Mirey Branch	19-41-5-3	SA	30502	Fecal coliform

[1] Classifications are defined in Table 3-1.

3.4 Stormwater and NPDES Program

3.4.1 Program Background

The National Pollutant Discharge Elimination System (NPDES) program was established under the CWA and then delegated to the NCDWQ for implementation in North Carolina. The NPDES Phase I permitting program for stormwater discharges was established in 1990 and focuses on site and operations planning to reduce pollutant sources. There are three types of activities that the Phase I program regulates through NPDES permits: industrial facilities, construction activities that disturb five or more acres of land, and municipal separate storm sewer systems (MS4s) serving populations of 100,000 or more (based on 1990 U.S. Census Bureau data) (NCDWQ, 2007a). [Note: MCBCL is classified as an industrial facility.]

Industrial facilities may be required to obtain permit coverage under a general permit or an individual permit, depending upon a facility's Standard Industrial Classification (SIC) code and the industrial activity occurring at the facility. One condition that is applicable to both the general permits and individual stormwater permits is the requirement to develop and implement site-specific, comprehensive stormwater pollution prevention plans (SPPP). These plans are required to include a comprehensive evaluation of the site and operations to reduce pollutant sources and prevent pollutant discharge. All stormwater management programs must include these six minimum control measures:

1. Public education and outreach on stormwater impacts
2. Public involvement/participation
3. Illicit discharge detection and elimination

4. Construction site stormwater runoff control
5. Post-construction stormwater management in new development and redevelopment
6. Pollution prevention/good housekeeping for municipal operations.

Construction sites that are five acres or more are required to develop and implement a site-specific erosion and sediment control plan. The issuance of the NPDES permit for subject construction activities is tied to plan approval by the North Carolina Division of Land Resources Erosion and Sediment Control Program (NCDWQ, 2007a).

Phase II of the NPDES stormwater program was signed into law in December 1999. This regulation builds upon the existing Phase I program by requiring smaller communities and public entities that own and operate an MS4 to apply and obtain an NPDES permit for stormwater discharges. The Phase II stormwater program applies to local governments that have been selected by automatic designation, state designation, or petitioning. Automatic designation applies to areas defined as Urbanized Areas by the U.S. Census Bureau. In general, an Urbanized Area is any local government or group of local governments that have a combined population of 50,000 and a density of 1,000 people per square mile. Based on the 1990 and 2000 Census data, Jacksonville, NC, was required to obtain and Phase II NPDES permit (NCDWQ, 2007b).

The NCDWQ has established specific stormwater treatment requirements for projects that meet designated criteria. All development in the 20 coastal counties identified by NCDWQ, including Onslow County and/or development draining to Outstanding Resource Water or High-Quality Waters, must meet specific stormwater requirements. Projects must also maintain low densities of impervious area. The low-density impervious area thresholds are typically between 12 and 30%, depending on the project location. In addition, projects must maintain vegetated buffers and transport runoff through vegetated conveyances. If projects cannot meet these criteria, they must install structural stormwater Best Management Practices (BMPs) capable of controlling the runoff from the 1 or 1.5 inch rain event. BMPs must also remove 85% of the total suspended solids (TSS) on an annual basis. Specific design requirements for various BMPs are specified in the states' BMP manuals (NCDWQ, 2007a).

3.4.2 MCBCL NPDES Permit

In 2004, MCBCL received an Individual Permit authorizing MCBCL to discharge stormwater from its storm drainage systems to waters of the state (Permit No. NCS000290). This permit required the development and implementation of a SPPP (AMEC Earth and Environmental, Inc., 2002). The SPPP outlines existing and proposed BMPs; identifies measurable goals and implementation schedules for the BMPs; and provides the anticipated cost of program implementation over the 5-year permit term. The SPPP is developed to ensure ongoing regulatory compliance with the six minimum control measures (previously described). MCBCL adopted and implemented its SPPP in 2002 prior to the final issuance of its permit.

MCBCL currently monitors seven outfalls every quarter. These samples are analyzed for chemical oxygen demand, TSS, total nitrogen, phosphorus, pH, and vinyl chloride, and the total flow of the discharge, duration of the rain event, and total amount of rainfall for the event are recorded. Results from the sampling program and any noncompliance activities must be reported to NCDWQ.

4. Endangered Species Act

As amended, the ESA of 1973 is federal legislation that is intended to provide a means to conserve the ecosystems upon which endangered and threatened species depend and to provide programs for the conservation of those species, thus preventing extinction of plants and animals. Depending on the species,

the law is administered by the U.S. Department of the Interior's Fish and Wildlife Service (FWS) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration Fisheries Service. The FWS has listed 45 species listed either as endangered species threatened species, federal species of concern, or candidate species as currently or historically occurring in Onslow County (U.S. FWS, 2007), and critical habitat has been designated for the piping plover.

4.1 Threatened and Endangered Species

As a federal agency, USMC is required under the ESA (16 U.S.C. 1531 et seq) to conserve (i.e., recover) listed species on its properties. Provisions in the 2004 National Defense Authorization Act allow military installations to be excluded from critical habitat designation given that the following are true: the INRMP (MCBCL, 2006a) provides (1) a benefit to the species; (2) certainty that the management plan will be implemented; and (3) certainty that the conservation effort will be effective.

MCBCL is home to eight federally listed species, which are considered either threatened (T) or endangered (E):

- Red-cockaded woodpecker (*Picoides borealis*) (E)
- Green sea turtle (*Chelonia mydas*) (T)
- Loggerhead sea turtle (*Caretta caretta*) (T)
- Rough-leaved loosestrife (*Lysimachia asperulaefolia*) (E)
- Seabeach amaranth (*Amaranthus pumilus*) (T)
- Bald eagle (*Haliaeetus leucocephalus*) (T)
- Piping plover (*Charadrius melodus*) (T)
- Leatherback sea turtle (*Dermochelys coriacea*) (T).

The American alligator (*Alligator mississippiensis*), which is found on MCBCL, is federally listed as threatened due to its similarity of appearance to the endangered American crocodile. The American alligator is however considered recovered, and actions that may affect it do not trigger Section 7 consultation with FWS. The endangered eastern cougar (*Puma concolor cougar*) is believed to be extirpated from Onslow County, NC.

Pondberry (*Lindera melissifolia*), a federally listed endangered plant, was reported on MCBCL in a single location in GSRA. Currently, however, the presence of pondberry on MCBCL has yet to be confirmed (MCBCL, 2006a).

4.1.1 Red-Cockaded Wodpecker (RCW)

In 2005, MCBCL supported 81 active RCW clusters. MCBCL's RCW population has increased 161% since 1986 (when intensive population monitoring began), from 31 clusters in 1986 to 81 active clusters in 2005 (MCBCL, 2006a). The *Mission-Compatible, Long-Range RCW Management Plan,* developed by MCBCL in coordination with the FWS, set a local recovery goal of 173 active clusters within 7 management areas on Mainside MCBCL (excludes GSRA). In the 2006 plan, RCW management on MCBCL falls into three categories: partition management (silviculture activities), cluster management and protection (protection from military activities), and population monitoring and management (demographics). MCBCL has more than 29 actions to attain the overriding goal of the establishment of 173 active RCW clusters.

4.1.2 Sea Turtles

Two species, the green sea turtle and the loggerhead sea turtle, are listed as threatened and nest on Onslow Beach at MCBCL. Three additional endangered species—the Atlantic hawksbill turtle, the Atlantic leatherback turtle, and the Kemp's Ridley turtle—occur in the waters off the coast of MCBCL,

but are not known to nest at the Base. From Mid-May through August, Base personnel conduct daily monitoring for sea turtle nesting. When nests are found in the designated training zone, they are relocated and monitored for hatchlings. The northern end of Onslow Beach, as well as Brown's Island, is off-limits to vehicular and foot traffic due to potential unexploded ordnance; therefore, aerial surveys are conducted twice a week during the nesting season (mid-May through August) to identify the presence of sea turtles.

4.1.3 Rough-leaved Loosestrife

Approximately 25 acres of habitat were occupied by rough-leaved loosestrife on MCBCL in 2006, and these areas have various land restrictions to preserve the habitat of hydrologic conditions of the area. These restrictions apply to the 100-foot buffer around these known populations. The Base has used GIS information to determine high-probability habitat for rough-leaved loosestrife and assess these areas prior to implementation of development or management activities.

4.1.4 Seabeach Amaranth

Seabeach amaranth is a plant that typically grows in overwash areas or along the beachfront. Because it is an annual plant, its location cannot be reliably predicted from year to year; therefore, all possible habitat locations are surveyed each summer. Once identified, sites with seabeach amaranth are identified to prevent disturbance, and plants are monitored for mortality.

4.2 Species at Risk

For the purposes of this document, species at risk will be defined as those species that are not federally listed, but are a conservation concern because of several factors, including the rarity of the species, the proportion of the species population occurring on MCBCL, and the potential of the species to impact the training mission if a species were to become listed. Species at risk for MCBCL include one Federal Candidate species, one Federal Species of Concern, and several state-listed species. MCBCL will protect populations of species at risk by designating Conservation Areas, as defined in the Protected Species Base Order (BO 5090.11.), where such restrictions do not negatively impact training.

4.3 Nursery Areas

The NCMFC has established rules to delineate and protect fragile estuarine areas that support juvenile populations of economically important seafood species. These rules set forth permanent nursery areas in all coastal fishing waters as defined through extensive estuarine survey sampling conducted by Marine Fisheries personnel. The NCMFC regulates estuarine waters, whereas the North Carolina Wildlife Resource Commission regulates inland nursery areas. Nursery areas are classified as (1) PNAs, (2) secondary nursery areas, or (3) special secondary nursery areas.

PNAs are located in the upper portions of creeks and bays surrounded by marshes and wetlands and are usually shallow with soft muddy bottoms. Low salinity and the abundance of food in these areas make them ideal for young fish and shellfish. To protect juveniles, many commercial fishing activities are prohibited in these waters, including the use of trawl nets, seine nets, dredges, or any mechanical methods for taking clams or oysters. Violators caught in a PNA face very substantial penalties.

Secondary Nursery Areas are located in the lower portions of creeks and bays, and trawling is not allowed these areas. As they develop and grow, young fish and shellfish, primarily blue crabs and shrimp, move into these waters.

Special Secondary Nursery Areas are located adjacent to Secondary Nursery Areas, but are closer to the open waters of sounds and the ocean. These waters are closed to trawling during the majority of the year, when juvenile species are abundant.

Appendix B

Prioritized List of MCBCL's Conservation and Water Quality Needs

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
High Priority Needs		
Primary Nursery Area (PNA) mitigation/delineation	Coastal Wetland	1. Research the determination of French Creek as a freshwater PNA. 2. Evaluate applicability of trading restoration credits. 3. Evaluate mitigation efforts that could lead to PNA boundary alterations.
Onslow Beach erosion	Coastal Barrier	1. Quantify long- and short-term shoreline change. 2. Identify erosion "hot spots" and their causes. 3. Predict shoreline changes based on various weather conditions and management scenarios.
Air quality/smoke management	Atmospheric and Other SERDP-funded project	1. Implement an ambient air monitoring program. 2. Identify ecosystem sensitivities, stressors, and contributors to nitrogen and carbon. 3. Transition information from two other SERDP-funded projects *Characterization of Emissions and Air Quality Modeling for Predicting the Impacts of Prescribed Burns at DoD Lands* (Talat Odman) and *Advanced Chemical Measurements of Smoke from DoD-Prescribed Burns* (Tim Johnson).
Measuring good quality habitat for red cockaded woodpeckers (RCW)	Other SERDP-funded project	Transition information from *A decision support system for Identifying and ranking critical habitat parcels on and in the vicinity of DoD Installations* (SI-1472; Jeff Walters)
N1/BT3 monitoring for whales/ marine mammals	Other SERDP-funded project	Transition information from *Predictive Spatial Analysis of Marine Mammal Habitat* (CS-1390; Andy Read/Pat Halpin/Larry Crowder/David Hyrenbach)
RCW flexibility for Range Development - Regional RCW credit	Other SERDP-funded project	1. Transition information from *Trading Habitat Patches for the RCW: Incorporating the Role of Landscape Structure and Uncertainty in Decision Making* (SI-1469; Michael Jones). 2. Transition information from *Habitat Connectivity for Multiple Rare, Threatened and Endangered Species On and Around Military Installations* (SI-1471; Aaron Moody)
Stormwater runoff reduction and water quality studies	Aquatic/ Estuarine	1. Employ sampling and analytical techniques to monitor water quality and develop methods for reducing runoff
Near field water quality studies	Aquatic/ Estuarine	1. Sampling and analysis of areas in proximity to wastewater effluent diffuser to characterize water quality.
Distinguish/quantify effects of point & non-point inputs nutrient, sediment and pathogen inputs.	Aquatic/ Estuarine	1. Bioassays of in situ nutrient and other pollutant effects on planktonic and benthic microalgae 2. Determine cause of algal blooms (nutrient and climate driven events).

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Water quality/ primary nursery areas	Aquatic/ Estuarine	1. Employ sampling/analytical techniques used for estuary
Physical-chemical-biological interactions & their control on WQ/habitat	Aquatic/ Estuarine	1. Deploy in stream, real-time physical/chemical profiling/sensing and sampling capabilities. Couple to nutrient-productivity dynamics and modeling
Medium Priority Needs		
Wetland (marsh) restoration opportunities in New River Estuary	Coastal Wetland	1. Evaluate past remediation efforts (shoreline stabilization). 2. Evaluate aerial extent of marshes based on historic aerial photographs. 3. Conduct water quality sampling and modeling to determine the wetland areas at greatest risk and where mitigation may be needed.
Species at Risk - beach amaranth	Coastal Barrier	1. Evaluate MCBCL's existing monitoring data. 2. Research ability to propagate and transplant species (no approach currently identified).
Species at Risk - sea turtles	Coastal Barrier	1. Evaluate MCBCL's existing sea turtle monitoring protocol and data. 2. Conduct research on hatchling predation.
Species at Risk - shorebirds	Coastal Barrier	1. Evaluate MCBCL's existing monitoring data. 2. Research use of overwash area on the south end of Onslow Beach.
Species at Risk - RCW	Terrestrial	1. Research stress hormone as indicator of RCW habitat quality and impacts of military training activity on RCW. 2. Determine habitat potential of pond pine (no approach currently identified).
Fire effects on vegetation, and quantifying/qualifying prescribed burns	Terrestrial	1. Determine ecosystems sensitivities to prescribe burn frequency and season. 2. Determine areas of good quality habitat.
Species at Risk - rough-leaved loosestrife	Terrestrial	1. Evaluate MCBCL's existing rough-leaved loosestrife monitoring protocol and data (no approach currently identified).
Habitat restoration and tactical vehicle off-road impacts	Terrestrial	1. Determine impacts of compaction from off-road vehicles on wiregrass (no approach currently identified). 2. Determine which training areas can best tolerate off-road vehicle use (no approach currently identified).
Northern Pocosin in Great Sandy Run Area (GSRA)	Terrestrial	No approach currently identified.
RCW monitoring	Other SERDP-funded project	Transition information from *Demographic and Population Response of Red-cockaded Woodpeckers on MCBCL to a Basewide Management Plan* (Jeff Walters)

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Additional military effects/RCW study	Other SERDP-funded project	Transition information from *Assessment of Training Noise Impact on the RCW* (CS-1083; Larry Pate)
Longleaf /loblolly decline	Other SERDP-funded project	Transition information from *Regenerating Longleaf Pine on Hydric Soils: Short- and Long-Term Effects on Native Ground-Layer Vegetation* (CS-1303; Joan Walker) and *Managing Declining Pine Stands for the Restoration of RCW Habitat* (SI-1474; Joan Walker)
Benthic organism Index of Biological Integrity (IBI)	Aquatic/ Estuarine	1. Use meiofaunal taxa composition to develop benthic indicators
Benthic-water column exchange and hypoxia research	Other SERDP-funded research	Transition data from *An Integrated Approach to Understand Relationships between Shallow Water Benthic Community Structure and Ecosystem Function* (CS-1335; Linda Schaffner/Iris Anderson)
Blue crab studies	Other	Transfer data from Martin Posey's (UNC-W) MCBCL funded study
Determine nutrient, sediment and pathogens loadings from the watershed; determine transformations of nutrients within the estuary. Determine interactive role of climatic/hydrologic roles	Aquatic/ Estuarine	1. Identify sources and loadings of nutrients, sediments and pathogens 2. Examine new vs. internally-regenerated nutrient sources and inputs 3. Determine inputs, effects and fates of nutrients, sediments and pathogens under hydrologically variable conditions 4. Model sediment-water column inputs and exchange of nutrients, sediments and pathogens
Identify and quantify nutrients controlling primary production, excess production and algal blooms	Aquatic/ Estuarine	1. Identify and quantify limiting nutrients 2. Identify and quantify sources of limiting nutrients 3. Establish thresholds of nutrient limitation and algal bloom 4. Target tributaries and estuarine segments not currently sampled. 5. Dynamic model to predict estuarine responses to nutrient inputs.
Determine causes and effects of harmful algal blooms (HABs). Link nutrient-productivity to hypoxia potentials	Aquatic/ Estuarine	1. Deploy microalgal indicators to examine HAB potentials and thresholds in water column and sediments 2. Develop indicators of productivity and community structure and assess stressor specific responses (algal blooms, hypoxia, food web perturbations)
Low Priority Needs		
Coliform counts - Freemans Creek (and other 303(d) TMDL identified tributaries)	Aquatic/ Estuarine	Pathogen tracking/source identification: 1. Differentiate between pathogen sources. 2. Partition nitrogen sources.

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Invasive species: alligator weed, *Phragmites*	Coastal Wetland	1. Determine aerial extent of *Phragmites*. 2. Determine affects of alligator weed on flood control (no approach currently identified).
Habitat restoration and tactical vehicle off-road impacts - maritime forest	Coastal Barrier	1. Survey biodiversity of maritime forests.